THE JOURNAL
OF THE
ROYAL AERONAUTICAL SOCIETY

(FOUNDED 1897 in succession to the ANNUAL REPORTS)

Edited for the Council by J. LAURENCE PRITCHARD, Fellow

No. 176 AUGUST, 1925 VOL. XXIX

NOTICES

Elections

The following Members were elected at a Council Meeting held on July 14th:

Associate Fellows.—Mr. C. Griffith Brewer, Squadron Leader E. L. Howard-Williams, M.C., Mr. R. A. Tarleton, and Flying Officer E. C. Wackett, R.A.A.F.

Foreign Member.—Mr. E. A. Stalker.

R.38 Memorial Prize, 1925

The R.38 Memorial Prize for 1925 has been awarded to Mr. R. A. Frazer, B.A., B.Sc., Associate Fellow, for his paper on "The Rigid Airship in Relation to Full-Scale Experiments."

The full paper will be published in an early issue.

Lecture Session, 1925

The following is the first half of the programme of lectures for next Session, so far as at present arranged. All the lectures will be held in the Society's Library, at 7, Albemarle Street, except that on November 3rd, which will take place at the Royal Society of Arts, John Street, Adelphi. Advance copies of all lectures may be obtained from the Secretary, price 6d. each, or 5/- for the whole series.

Oct.	1.	5.30.	Major-General Sir Sefton Brancker, K.C.B., A.F.C. "The Technical Lesson of Five Years of Air Transport."
,,	15.	5.30.	Major C. K. Cochran-Patrick, D.S.O., M.C. "Aircraft Survey in Burma."
,,	29.	5.30.	Mr. W. L. Cowley. "Aircraft Transport Economy."
Nov.	3.	7.0.	Sir Dugald Clerk, K.B.E., F.R.S., D.Sc., M.I.Mech.E., M.Inst.C.E., F.R.Ae.S. "Supercharging."
,,	12.	5.30.	Mr H. B. Howard, A.F.R.Ae.S. "Some Problems in Aeroplane Structural Design."
,,	26.	5.30.	Mr. A. H. R. Fedden, F.R.Ae.S. "Installation Problems in Air-Cooled Engines."
Dec.	3.	5.30.	Professor B. Melvill Jones, A.F.C., A.F.R.Ae.S. "The Control of Stalled Aeroplanes."
,,	10.	5.30.	Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S. "The Evaporative Cooling of Aero Engines and Condensation of their Exhaust Gas."
,,	17.	5.30.	Mr. A. J. Cobham. "Long-Distance Aeroplane Flights."

Australasian Association for the Advancement of Science

A meeting of the Australasian Association for the Advancement of Science has been arranged to take place in Perth, Western Australia, in August, 1926. Section "H" (Engineering and Architecture) should be of great interest to Members.

Extension of the Activities of the Society

The attention of all grades of members of the Society is particularly called to the proposed extension of the activities of the Society outlined on page 399.

J. LAURENCE PRITCHARD,

Hon. Secretary.

THE WILBUR WRIGHT MEMORIAL FUND.

In the AERONAUTICAL JOURNAL for August, 1920, the Wilbur Wright Memorial Fund was reported on page 415 up to the 31st May, 1920. The present statement reports the progress of the fund and of the Wilbur Wright Lectures up to the 30th June, 1925.

This is a favourable opportunity for drawing attention to the growing importance of the Wilbur Wright Memorial Lecture. Several monuments have been erected to the work of Wilbur Wright, but the Wilbur Wright Memorial Lecture is the first active memorial, which year by year commemorates the work of Wilbur Wright by giving a further addition to the science of aeronautics, the actual practice of which was founded by the namesake of the fund. In honouring Wilbur Wright we do not forget that Orville Wright was equally associated with him in the stupendous advance in science brought about by the joint efforts of these courageous brothers.

The following is a list of the present survivors of the Trustees of the Wilbur Wright Memorial Fund:—

Griffith Brewer,
Lieut.-Colonel F. K. McClean,
Lieut.-Colonel Alec Ogilvie,
Colonel H. E. Rawson,
Major-General Sir R. M. Ruck, and
B. Woodward.

It is deeply regretted that two of the original Trustees, Professor T. A. Hearson and the Right Honourable the Lord Northcliffe, have died since the last report of the fund.

The lectures which have been delivered up to date are as follows:—

Year.	Lecturer.	Title.
1913	Sir Horace Darwin, F.R.S. ..	Scientific Instruments, their Design and Use in Aeronautics.
1914	Sir R. T. Glazebrook, F.R.S. ...	The Development of the Aeroplane.
1915	Professor G. H. Bryan, F.R.S. ...	The Rigid Dynamics of Circling Flight.
1916	Griffith Brewer	The Life and Work of Wilbur Wright.
1917	Lieut.-Col. Mervyn O'Gorman, C.B.	Looking Ahead.
1918	Dr. W. F. Durand, U.S. Nat. Adv. Com. Ae.	Some Outstanding Problems in Aeronautics.
1919	Leonard Bairstow, F.R.S., C.B.E.	Progress of Aviation in the War Period.
1920	Commander J. C. Hunsaker, U.S. Navy	Naval Architecture in Aeronautics.
1921	G. I. Taylor, F.R.S.	Scientific Methods in Aeronautics.
1922	Lieut.-Col. A. Ogilvie, C.B.E. ...	Some Aspects of Aeronautical Research.
1923	Dr. Joseph S. Ames, U.S. Nat. Adv. Com. Ae.	Relation between Aeronautic Research and Aircraft Design.
1924	Lieut.-Col. H. T. Tizard, A.F.C.	Fuel Economy in Flight.
1925	Rear-Admiral D. W. Taylor, U.S. Navy, U.S. Nat. Adv. Com. Ae.	Some Aspects of the Comparison of Model and Full-Scale Tests.

The account of the Wilbur Wright Memorial Fund up to the 30th June, 1925, is given below:—

THE WILBUR WRIGHT

Statements of Receipts and Payments,

Dr.

		£	s.	d.
1920.				
July 1.	To Balance at Bank	192	18	4
Oct. 2.	,, Dividend on £550 Canada 4% Stock, 1940-60 ...	8	13	3
Sept. 1.	,, Dividend on £800 War 3½% Stock	9	16	0
Nov. 11.	,, Inland Revenue (Repayment of Income Tax) ...	38	17	10
1921.				
Mar. 1.	,, Dividend on £800 War 3½% Stock	9	16	0
Apr. 2.	,, Dividend on £550 Canada 4% Stock	8	7	1
Sept. 1.	,, Dividend on £800 War 3½% Stock	9	16	0
Oct. 3.	,, Dividend on £550 Canada 4% Stock	7	14	0
1922.				
Mar. 1.	,, Dividend on £800 War 3½% Stock	9	16	0
Apr. 3.	,, Dividend on £550 Canada 4% Stock	7	14	0
Sept. 1.	,, Dividend on £800 War 3½% Stock	10	10	0
Oct. 4.	,, Dividend on £550 Canada 4% Stock	8	5	0
Nov. 21.	,, Inland Revenue (Repayment of Income Tax) ...	36	18	10
1923.				
Mar. 1.	,, Dividend on £800 War 3½% Stock	10	10	0
Apr. 5.	,, Dividend on £550 Canada 4% Stock	8	5	0
Sept. 1.	,, Dividend on £800 War 3½% Stock	10	17	0
Oct. 3.	,, Dividend on £550 Canada 4% Stock	8	10	6
1924.				
Mar. 1.	,, Dividend on £800 War 3½% Stock	10	17	0
Mar. 1.	,, Dividend on £550 Canada 4% Stock	8	10	6
July 16.	,, Inland Revenue (Repayment of Income Tax) ...	17	10	0
Sept. 1.	,, Dividend on £800 War 3½% Stock	10	17	0
Oct. 2.	,, Dividend on £550 Canada 4% Stock	8	10	6
1925.				
Mar. 2.	,, Dividend on £800 War 3½% Stock	14	0	0
Apr. 2.	,, Dividend on £550 Canada 4% Stock	8	10	6
June 24.	,, Inland Revenue (Repayment of Income Tax) ...	8	2	0
		£484	2	4

MEMORIAL FUND.

July, 1920, to June, 1925.

					Cr. £	s.	d.
1920.							
July 15.	By Purchase of £200 War Loan 3½% Stock, 1925-8, @ £84	£168	0	0			
	Commission	0	10	0			
	Cont. stp.	0	1	0			
					168	11	0
Dec. 16.	,, Wright, Wake, Price and Co. (Preparing Claim for Repayment of Income Tax)				3	3	0
1921.							
June 7.	,, Premium to G. I. Taylor for Ninth Wilbur Wright Lecture				50	0	0
1922.							
July 27.	,, Premium to Lieut.-Col. Alec Ogilvie for Tenth Wilbur Wright Lecture				50	0	0
Dec. 19.	,, Wright, Wake, Price and Co. (Preparing Claim for Repayment of Income Tax)				3	3	0
1923.							
June 1.	,, Premium to Dr. Joseph S. Ames for Eleventh Wilbur Wright Lecture				50	0	0
1924.							
May 29.	,, Premium to Lieut.-Col. H. T. Tizard for Twelfth Wilbur Wright Lecture				50	0	0
1925.							
Apr. 30.	,, Premium to Rear-Admiral D. W. Taylor for Thirteenth Wilbur Wright Lecture				50	0	0
June 30.	,, Balance at Bank				59	5	4
					£484	2	4

GRIFFITH BREWER,
Hon. Sec. to the Wilbur Wright Memorial Fund.

8th July, 1925.

ALUMINIUM ALLOYS FOR AEROPLANE ENGINES*

BY PROFESSOR F. C. LEA, D.SC., M.INST.C.E.

Introduction

In the early days of the war the desirability of reducing the weight of aeroplane engines to a minimum, consistent with reliability and efficiency, very soon led designers to consider the advisability of using alloys considerably lighter than cast iron or steel for all possible parts of aero engines. Aluminium alloy crank cases had been used for some years in connection with motor car engines, and it was natural, therefore, that such alloys should come into use for the crank cases of aeroplane engines. Alloys of aluminium suitable for this purpose can be made, having a specific gravity not more than three, and having an ultimate breaking strength very nearly equal to that of cast iron. It was only necessary, therefore, to overcome foundry difficulties in order that such alloys should be generally used. The light alloys have a distinct advantage over the heavier cast iron for such purposes as crank cases, in that for anything like the same weight the crank case can be made much thicker and consequently more rigid,† and less liable to local damage. The mean modulus of elasticity of cast iron is, however, greater than that of aluminium, at least one and a half times as great, and the rigidity of aluminium under elastic stresses is less, therefore, than cast iron for the same range of stress. The necessity, however, from the point of view of the foundry, of not making castings too thin, and also that they shall be sufficiently rigid, means that in any case the range of stress cannot as a rule be very great, and alloys having a high ultimate stress cannot, from this point of view, be economically used; thus, alloys having a tensile strength, when cast in the sand, of from 8 to 12 tons per inch have generally been found satisfactory. A note of warning is required here, as it is very doubtful whether in such alloys tensile strength is altogether a satisfactory criterion of their suitability for certain purposes; it will be seen later that the total stress range under repetition stresses is not more than half the ultimate tensile strength of these alloys. One alloy may conceivably have a higher tensile strength than another and yet its elastic range, or again its resistance to repetition stresses, may not be any better than an alloy of lower tensile strength. Alloys of aluminium containing from 2 to 3 per cent. of copper and, say, 30 per cent. of zinc can be made, having an ultimate breaking strength of nearly 20 tons per sq. inch, but such an alloy has a specific gravity well over three, is very brittle, and in the foundry and machine shop would be likely to prove difficult to manipulate. In ordinary crank case work, bosses and bearings, and the difficulties of running limit the thinness of the casting, and in the machine shop thin brittle castings, especially when they have to be drilled and tapped, are difficult to handle. Alloys having from 2 to 3 per cent. of copper and from 10 to 14 per cent. of zinc are easy to make, they have a density less than three, and have been found to give fairly good results both in the foundry and machine shop. During this last three years an alloy known as L5, first made by Dr. Rosenhain, containing from 12 to 14 per cent. of Zn and 2½ to 3 per cent. Cu, has been largely used, and experience has shown that with reasonable care good castings can be produced and the machine shop scrap need not be very high. Alloys having higher percentage of zinc and less copper have been used, but considerable difficulty has been experienced by cracks developing during the machine operations. The L5 alloy is not by any means perfect, but it has a reasonable tensile strength and

* Reprinted, the original paper being out of print.—ED.

† Rigidity is here used in a rather loose sense. The periodicity of two elements of a machine of similar form would be inversely proportional to the square root of the modulus of elasticity.

elongation per cent., and it is not difficult to make in the foundry. The alloy, in addition to being used for crank cases, has been found suitable for many of the smaller parts of engines that can suitably be made in an aluminium alloy, such as induction pipes, carburettors and centrifugal pumps. It is very doubtful whether it is the best alloy to be used when non-porosity for gases or liquids is required; by using suitable dopes such castings have, however, been made quite impervious to fluids.

The success gained by using aluminium alloys for crank cases, etc., suggested the desirability of using them for pistons and cylinders, and for such purposes the alloys have certain excellent qualities. It is well known that the efficiency of the four-stroke cycle internal combustion engine is theoretically proportional to the compression ratio. In an aeroplane engine it is also desirable that the power per unit volume shall be as large as possible. To obtain high efficiency and large power per unit volume, while at the same time avoiding pre-ignition, the piston and cylinder should be of a good conductor and so designed that heat can be effectively transmitted through the cylinder walls to the cooling fluid, whether air or water. Experience seems to show that the heat taken away by the cooling fluid is about equal to the effective work done; *i.e.*, if 25 to 30 per cent. of the heat of combustion is obtained at the brake, a nearly equal amount will be carried away in the cooling system. Now an aluminium alloy may have a conductivity coefficient more than three times that of cast iron, and in the case of the piston the possibility of making the walls thicker, for the same weight as the cast iron piston, makes it probable for a double reason that an aluminium piston will run much cooler than a cast iron piston and, therefore, makes possible higher compression ratios.

The advantages to be obtained from using aluminium cylinders are, however, not quite so obvious. The flow of heat through any body is proportional to the difference of temperature between the hot and cold surface, is inversely proportional to the distance between the hot and cold surface and directly proportional to the conductivity.

Let two cylinders of cast iron and aluminium respectively be made the same weight and similar in form. Assume the same quantity of heat to flow through them. Let ρ and ρ_1 be the densities of the metals, k and k_1 the conductivities and t and t_1 the mean thicknesses of the surfaces of the cylinder through which heat escapes to the cooling fluid. Then since the weights are the same

$$\rho/\rho_1 = t_1/t$$

Let T and T_1 be the temperature of the hot wall of the cast iron and aluminium cylinders respectively and T_0 the temperature of the cold wall in each case, then the heat flow through

$$C.I./Al = H/H_a = (T - T_0)kt_1/(T_1 - T_0)tk_1$$

Assume T equal to T_1, then

$$H/H_a = kt_1/k_1t = k\rho/k_1\rho_1$$

k/k_1 may be taken as 3, and $\rho/\rho_1 = 2.7$; then $H_a/H = 1.25$.

For the same weight of cylinder it might be expected that there would be a gain, therefore, by using aluminium instead of steel or cast iron. By further reducing the weight, and thus the thickness, a greater gain could be made. If the wall of the aluminium could be made the same thickness as the plain steel or cast iron cylinder the heat carried away for the same temperature difference would be much greater, or, for the same heat carried away, the aluminium cylinder would be the cooler. The fact, however, that the aluminium cylinder cannot be made as thin as a steel cylinder, and that a liner must be put into the aluminium cylinder, would appear to make it doubtful whether the aluminium cylinder has, from the point of view of conductivity of heat to the cooling fluid, any advantage over the cast iron or steel cylinders. What then is to be gained by using

aluminium cylinders? Probably the greatest gain is what might be called an indirect advantage, in that an aluminium cylinder having, for the same weight, thicker walls, especially in the neighbourhood of the exhaust parts, and a much better conductivity than a cast iron or steel cylinder, tends to keep a more uniform temperature than the iron or steel cylinder, or in other words there is less tendency for local overheating; if a cylinder can be kept uniform in temperature at, say, 200° C. it is less likely to give trouble from the point of backfiring and distortions than another cylinder having the same mean temperature, but in which there is a considerable range of temperature. For water cooled engines steel cylinders, directly in contact with the water in the jacket, provided these can be made stiff enough, with a high conducting alloy for the cylinder head would appear to be the ideal combination

Aluminium Cylinders

Air cooled and water cooled cylinders have been made in aluminium alloys. At the R.A.E. very complete tests were carried out on cylinders 100 m.m. diameter by 140 m.m. stroke and cylinders 114 m.m. diameter by 140 m.m. stroke. The alloy generally used was copper 7%, zinc 1%, tin 1%, aluminium 91%. The cylinders were fitted with steel open-ended liners so that the hot gases came into contact with the aluminium alloy at the top of the combustion space. The general design of these cylinders is shown in Figure 1. It will be seen that considerable care has been taken to cool the exhaust ports effectively; this is important as too great care cannot be taken to insure sufficient cooling near the valve ports. Overheating is bound to lead to cracking across the port and the cooling surface must be sufficient to keep the temperature well below 300° C.

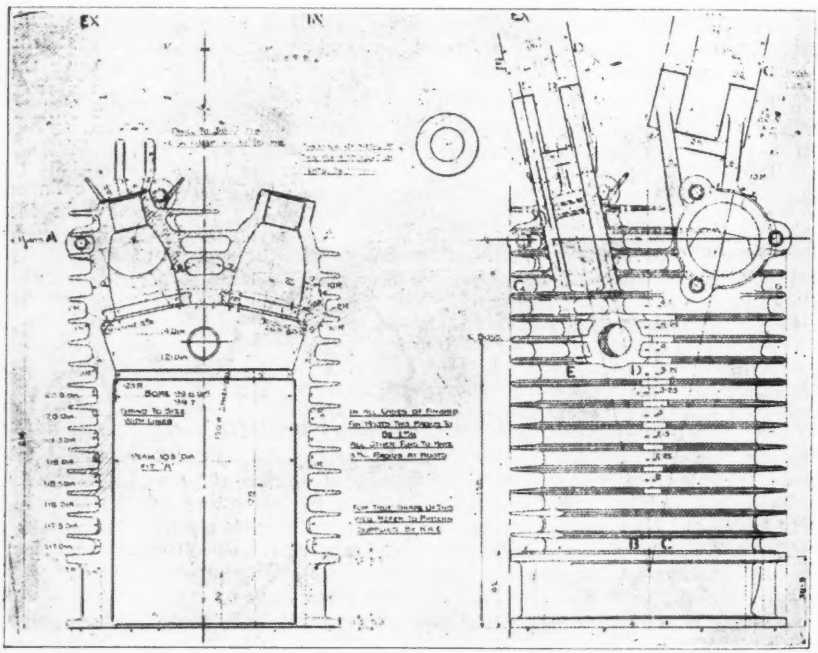

Fig. 1.

In the case of another experimental engine not tested at the R.A.E., in which the temperature reached 320° C. in the neighbourhood of the exhaust port, the cylinders always cracked after a few hours run. The total area of the cooling surfaces of these R.A.E. cylinders is as follows :—

Cylinder.	Surface, sq. ft.	Pitch of fins.
100 × 140 m.m. aluminium cylinder	... 6.14	12 m.m.
114 × 140 m.m. ,, ,,	... 8.4	9 m.m.
100 × 140 m.m. cast iron ,,	... 4.7	8 m.m.

Tests were carried out on the 100 m.m. × 140 m.m. cylinder at speeds of 1,400, 1,600 and 1,800 r.p.m. The velocity of the cooling air at a point 6in. ahead of the centre of the cylinder was 64 miles per hour. Pitot tube measurements showed that this gave the same mean velocity for the whole cooling surface as a parallel air current of 58 miles per hour. The air temperature was approximately 60° Fahrenheit.

The thermal efficiency of the engine was never less than 25%, and the efficiency ratio as compared with the air cycle was 58%. At a speed of 1,800 r.p.m., compression ratio 4.6, and at maximum load mixture, the petrol consumption was .575 pints per break horse power hour, and .530 pints with the weak mixture. In a cast iron cylinder running at 1,800 r.p.m. the petrol consumption was .770 pints per break horse power hour.

The maximum temperature recorded in the aluminium cylinder was 175° and the minimum temperature 129°. The maximum liner temperature was 144°. In the cast iron cylinder the maximum temperature recorded was 268° and the minimum temperature 171°. It will be seen, therefore, that the tests fully justified the substitution of the aluminium air cooled cylinder for the cast iron cylinder, and at one time it was intended to manufacture on a large scale the R.A.E. engine with aluminium cylinders, but, presumably, the demands from squadrons for higher power engines led to the abandonment of the R.A.E. aluminium cylinder engine; in this engine each cylinder was an independent unit.

In the Bentley rotary engines, B.R.1 and B.R.2, cylinders as independent units were also used, and into each of these a steel liner was fitted. The cylinder barrels were cast in chills in an alloy containing 12% copper. As cast the cylinders were plain barrels, as shown in Figure 2. The finished cylinders are

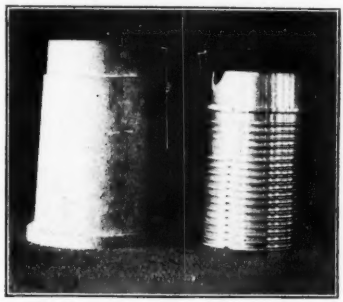

Fig. 2. Fig. 3.

shown in Figure 3; all the ribs are turned in the lathe; the necessity for perfect balance in a rotary engine made this desirable. In this engine a cast steel valve head was bolted to the crank case by long bolts running parallel to the axis of

the cylinder. Experience showed that it was desirable and possible to make the joint between the valve head and the cylinder without packing, and the hot gases in the cylinder did not, therefore, come in contact with the aluminium alloy.

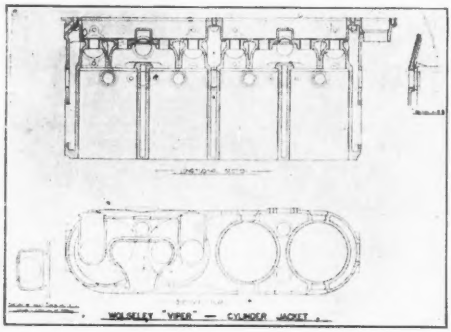

Fig. 4.

Water Cooled Engines

Four types of engines having water cooled aluminium cylinders have been used on a large scale:—

(1) The Hispano Suiza Engine,
(2) The B.H.P. Puma Engine,
(3) The Sunbeam Arab Engine,
(4) The Sunbeam Maori Engine.

The Hispano Suiza Engine.—This is an eight-cylinder Vee engine, the cylinder blocks on each side of the engine having four cylinders in each block.

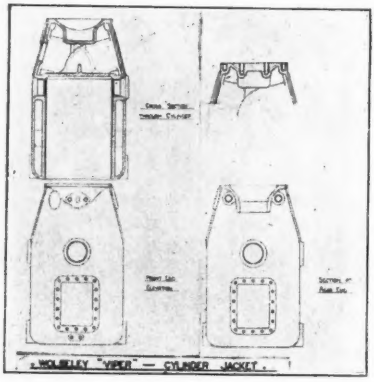

Fig. 5.

A cross section of the aluminium water jacket is shown in Figure 4. Into each of the barrels is screwed a steel liner, closed at the top end except for the holes forming the valve seats. The products of combustion, therefore, do not come in contact with the aluminium. The liners are screwed into the jackets at the

ordinary temperatures, and contact between the liner and the aluminium, therefore, depends entirely upon the accuracy of the machining. It is probable that certain troubles, to which we shall refer later, that have been met with in connection with this engine are to a certain extent due to this method of procedure. Figure 5 shows a transverse section of the jacket. Figure 6 is a photograph

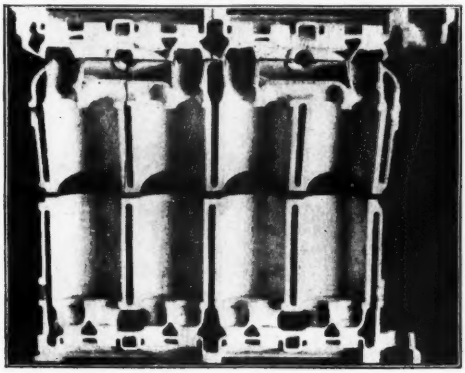

Fig. 6. Showing Hispano engine aluminium cylinders sectioned so as to show water jackets and ports.

showing the jacket cut through. Figure 7 shows an outside view of the jacket. Figures 8 to 13 show the cores and the moulding boxes for the Hispano jacket. Figure 14 shows the mould being poured. It will be seen that the mould is built up in two boxes, these boxes being turned on end for pouring the mould; the

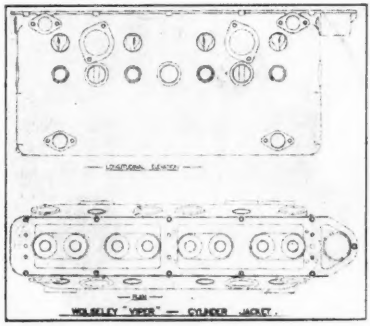

Fig. 7.

tops of the barrels have large risers and two pots are used for pouring the mould. Figure 15 shows a general view of the engine. The Hispano jackets are made of an alloy containing 8% copper, 6% zinc, 86% aluminium; they required doping to make them watertight and the percentage of foundry scrap was considerable; otherwise the alloy was satisfactory and proved strong enough under working conditions.

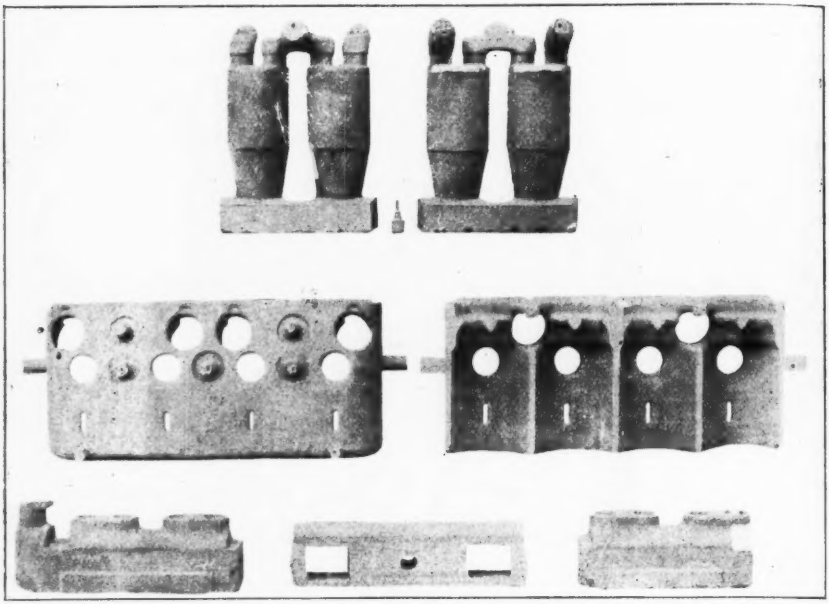

Fig. 8.

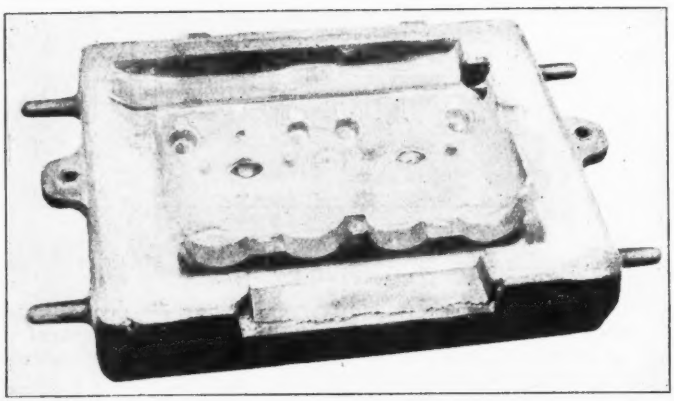

Fig. 9.

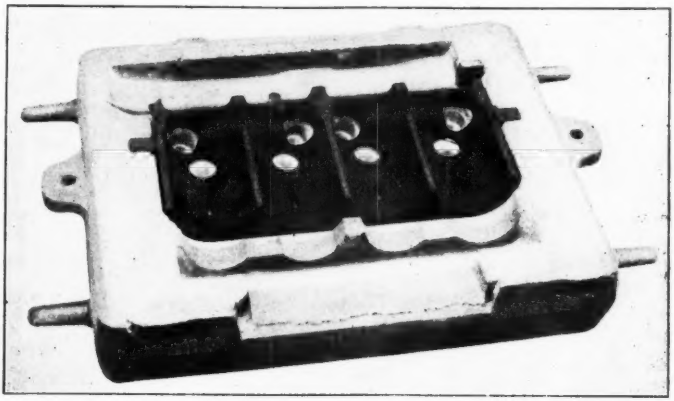

Fig. 10.

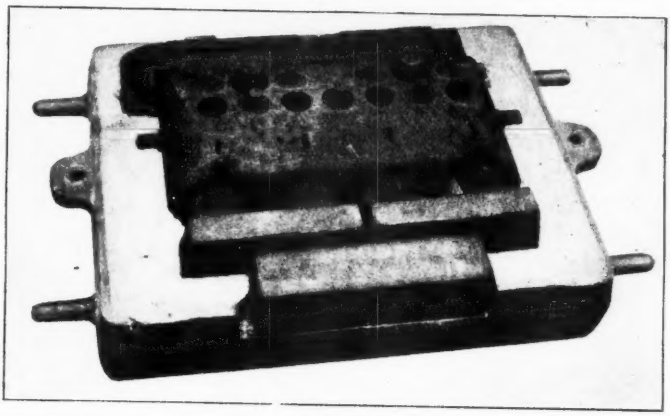

Fig. 11.

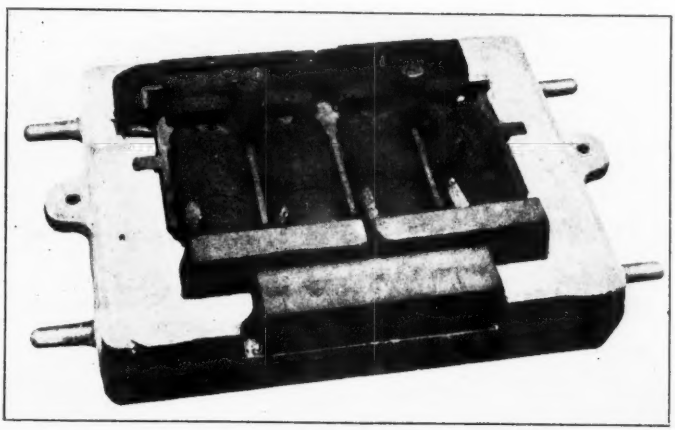

Fig. 12.

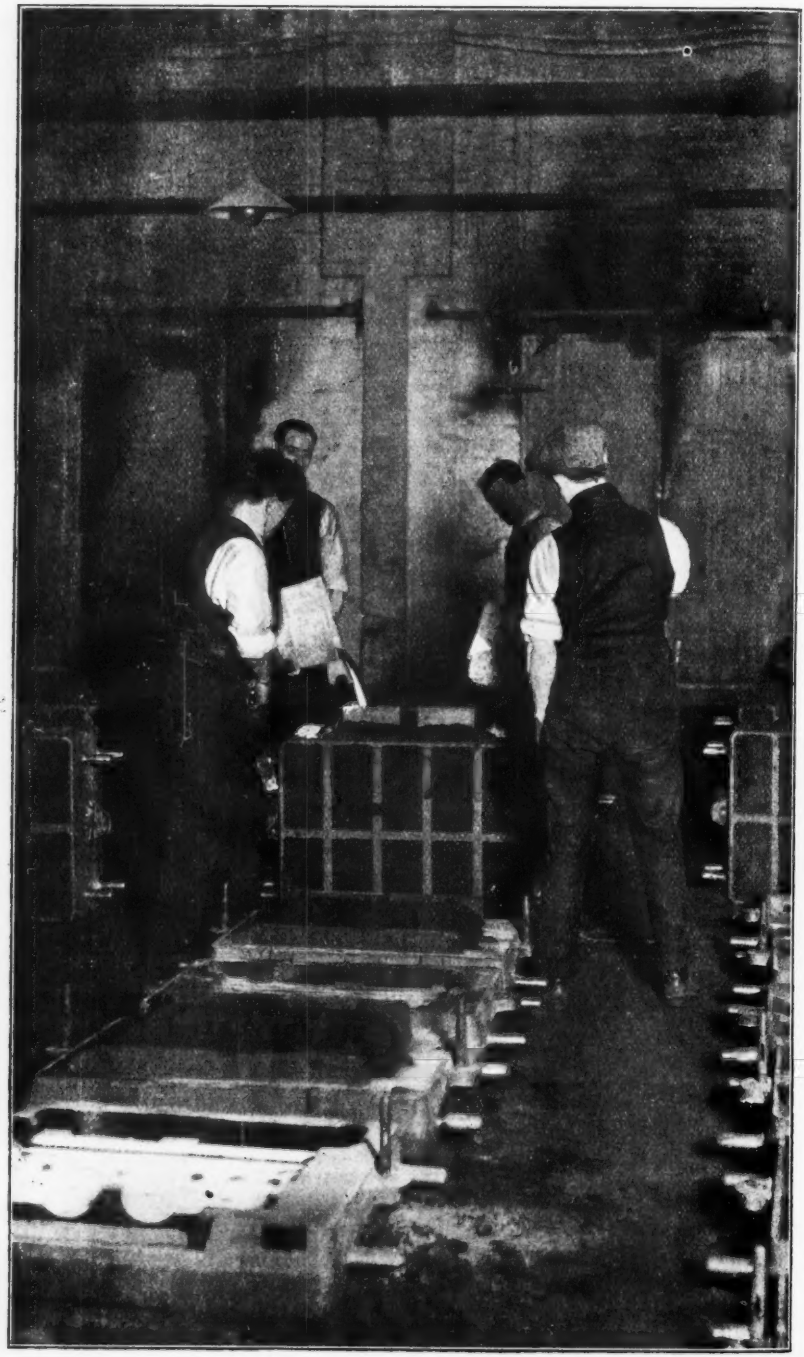

Fig. 14.

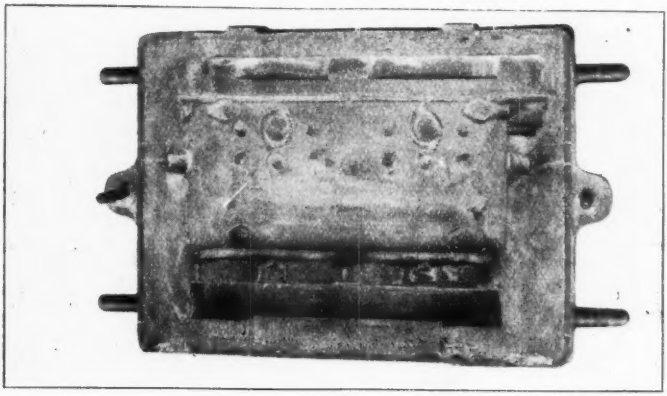

Fig. 13.

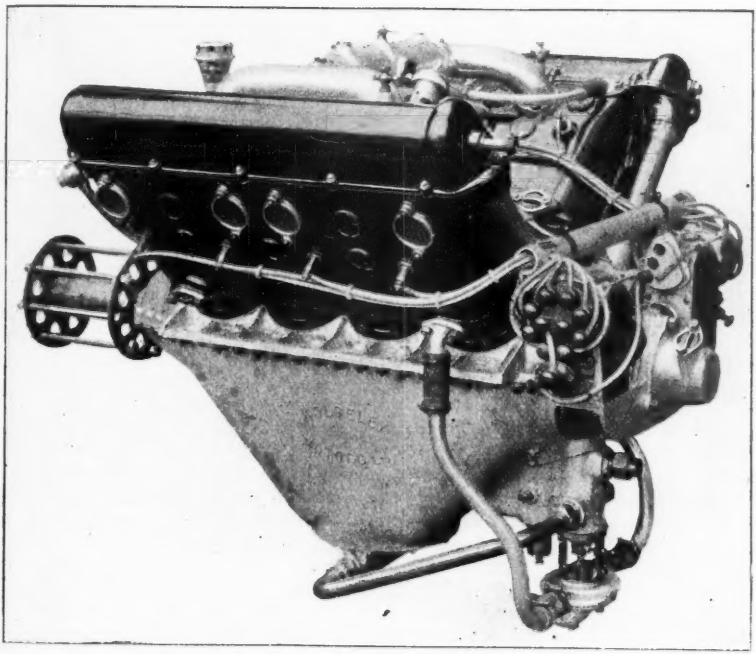

Fig. 15.

*The B.H.P. Puma Engine.**—The Puma engine is a vertical six-cylinder engine with the cylinders in two blocks of three, called right and left. A steel liner is screwed into each barrel of the aluminium cylinder head, the water jacket being completed by a simple aluminium jacket bolted to the cylinder head by 42, ¼in. diameter bolts. A stuffing box is formed at the bottom of this jacket by means of a rubber ring and a brass ring screwed on to the liner. It was originally intended to make the cylinder head and jacket in one piece, but principally because of foundry difficulties this was abandoned. Figure 16 shows the three-cylinder block without the liners and Figure 17 the boxes for moulding the jacket with the cores in position. Difficulty was experienced in the early days of this engine in obtaining sound and watertight castings and various methods of doping were tried without very great success until the writer suggested the use of sodium silicate. Considerable trouble was also experienced with the cylinder blocks cracking when in service, and in some cases it was thought that the cracking commenced between the valve seats. After

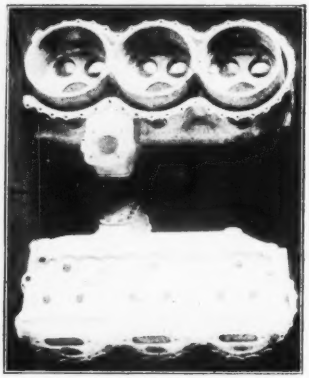

Fig. 16.

careful examination we, however, formed the opinion that the cracking commenced, if not in all, in the majority of cases at the outer end of the screwed portion of the jacket, Fig. 16. As referred to in detail later, the diameter of the screwed portion of the jacket was made smaller than the liner and the liner was inserted while the jacket was hot. The final hydraulic test of the cylinder block was generally made after the loose jacket had been put into position, and the packing gland screwed home. Under these circumstances it was difficult, if not impossible, to discover any small leaks that occurred between the liner and the cylinder head, and thus small cracks that may have occurred when the liner was inserted into the cylinder head were overlooked. When the glands were loosened and the jacket raised during the final internal hydraulic test it was found in a number of cases that there were small cracks at the end of the screwed portion of the cylinder head. Such cracks had very probably occurred in other cylinders that had gone into commission, which cracks developed until they had traversed the whole length of the barrel and right across the cylinder head. I had not the opportunity of seeing all the cylinders that did crack, but in a considerable number that I examined, in nearly all cases it seemed clear that the cracks had commenced at the open end of the aluminium barrel. Certain it was that cylinders having cracks in nearly all stages of development, very short cracks at the open end,

* Owing to printing difficulties, drawings of this engine had to be omitted from the text.

cracks extending half way down the barrel, cracks extending from top to bottom of the barrel and cracks extending from the top of the barrel right across the valve seats were found. In only a few cases were the cracks found across the valve seats only. The possibility, however, of the cracks having developed at the valve seats led to a careful inquiry as to the amount of expansion of the phosphor bronze or manganese bronze valve seats which could safely be allowed, and very great care was exercised to limit the amount of expansion. In order that it could not exceed a specified amount Messrs. Weirs used a special tool, shown in Figure 18, which not only expanded the seat, but which also by pressure burred over the aluminium at the outer edge of the brass valve seat.

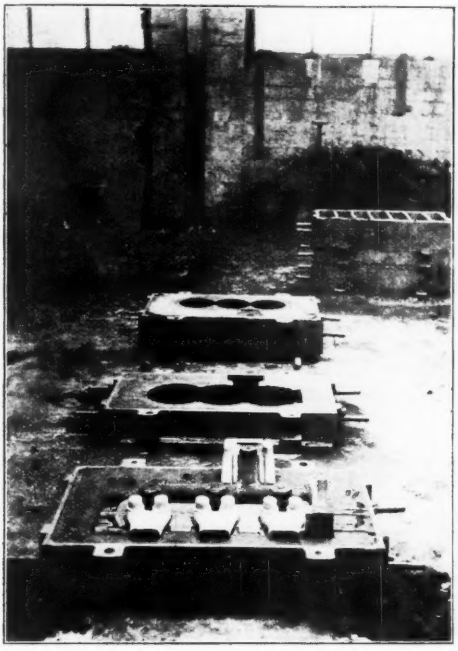

Fig. 17.

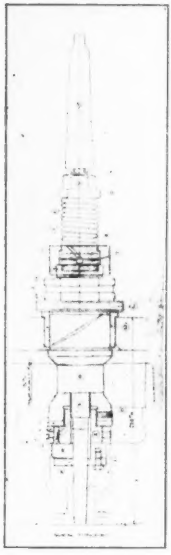

Fig. 18.

It may not be out of place here to refer to the importance of very careful consideration being given, in the design of the heads of combustion spaces, to see that when the valve seats are inserted the metal round the seat should not be below the edge of the seat, and it should not project too much to prevent it being effectively caulked on to the valve seat. In this connection the Puma engine had, I think, one distinct advantage over the Sunbeam engine, in that since the combustion space head was machined, and the caulking allowance was much more under control, very much less hand work was required.

The lower end of each of the steel liners of the Puma engine has a stiff flange; stiff clamps, which rest on flanges, are bolted to the crank case and hold the cylinder blocks in position. This has a distinct advantage over the Sunbeam method of attachment, inasmuch as local variable stresses on the foot of the cylinders, which may be considerable, are taken by steel and not by aluminium. Later some figures are given of the fatigue ranges of stress of aluminium alloys.

Experience with the Sunbeam Arab engine and with other aluminium cylinders shows that, especially with somewhat brittle alloys, there is considerable risk of the feet of the cylinder blocks breaking off after a certain period of running; the cracking is more likely to occur if the crank case has not considerable stiffness. Experiments, which were carried out on the Sunbeam and Hispano Suiza crank cases, showed that under torsional couples the Sunbeam crank case was very much less stiff than the Hispano Suiza crank case, and it seems more than probable that the lack of rigidity may have contributed to the failure. This view seems to be supported by the fact that in addition to trouble with cracked feet there was considerable trouble with the oil well of the Sunbeam engine cracking near to the gear wheel housing, and it was near to the housing that the cylinder blocks generally cracked. As originally designed, Figure 19, the Sunbeam oil well,

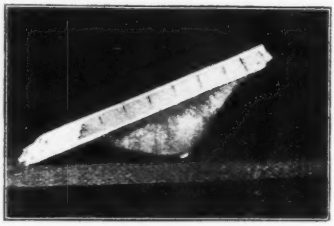

Fig. 19.

was apparently insufficiently stiff, and an attempt was made to stiffen it at the section just behind the gear housing. A further deepening of the well would, I think, have been an improvement, but without considerable alterations in other respects this was found impossible.

In this connection it is of interest to refer to a simple elementary point, which is unfortunately sometimes overlooked by designers. In a geared engine the torque on the crank case can be very much more than the torque on the crank shaft or on the propeller shaft.

Let T be the crank shaft torque. The pressure P, Fig. 20, between the

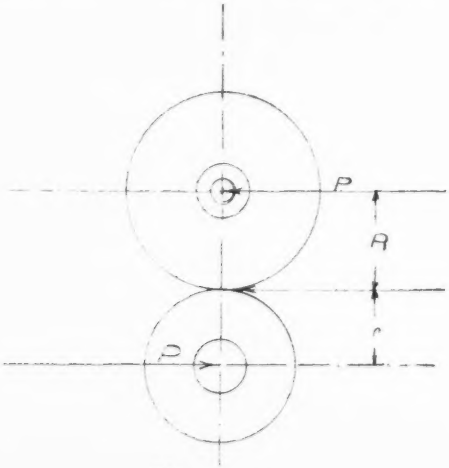

Fig. 20.

teeth of the crank shaft pinion of radius r and the propeller shaft pinion of radius R will be

$$P = T/r$$

The torque on the propeller shaft is

$$T_1 = PR$$

The reaction at the crank shaft pinion bearing and also at the propeller shaft bearing will be P. The couple formed by this reaction is $P(R+r)$.

Therefore,

$$\text{Couple on crank case/Couple on crank shaft} = (R+r)/r$$

If the gearing is 3 to 5 the crank case couple $= 8/3$ crank shaft couple.

The weakest section is just behind the gear case and it was here, both with the cylinders and the oil well, that trouble was experienced in the Arab engine.

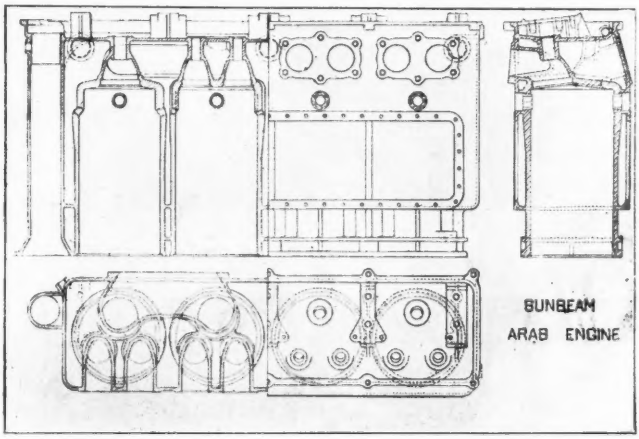

Fig. 21.

The Sunbeam Arab Engine.—The Sunbeam Arab engine is an eight-cylinder Vee engine, with the four cylinders and jackets on each side of the Vee cast in one block, Figure 21. A steel liner, open at both ends, is inserted in each barrel; the inner end of the liner finishes at some distance from the crown of the barrel and the lower end of the liner is finished flush with the end of the barrel. Figures 22 to 26 show views of the cores and the moulding boxes; Figure 27 shows the finished block when first taken from the mould. The large headers on the cylinder barrels can be clearly seen. Figure 28 shows the cylinder block after dressing. As already remarked, in the early days of this engine, trouble was experienced with the feet of the cylinder blocks cracking, particularly near to the bearing housing, and the liner was therefore flanged as shown in Figure 29, in the hope that the flange of the liner would assist in taking the stresses. I think, perhaps, this experiment was not as successful as it might have been if a little more care had been taken to see that the flange of the liner was in actual contact with the aluminium, but even if the steel were in contact with the aluminium the effect of the steel flange would be very small unless the thickness of the steel was very nearly equal to that of the aluminium.

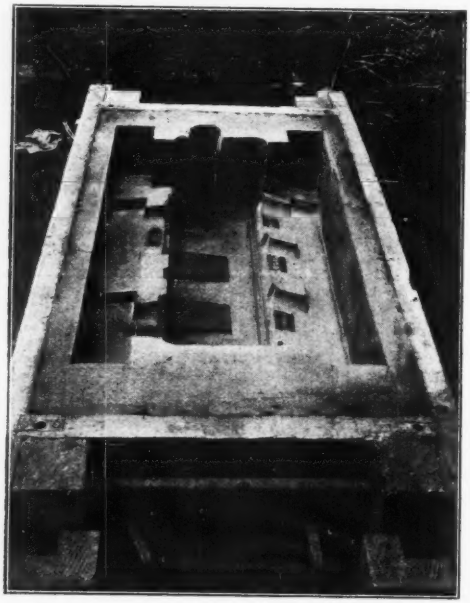

Fig. 22.

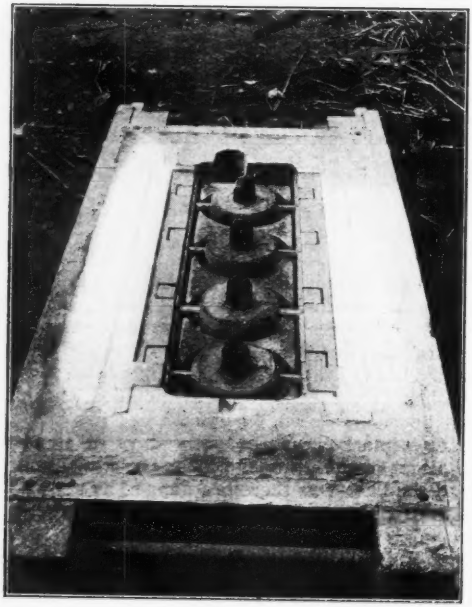

Fig. 23.

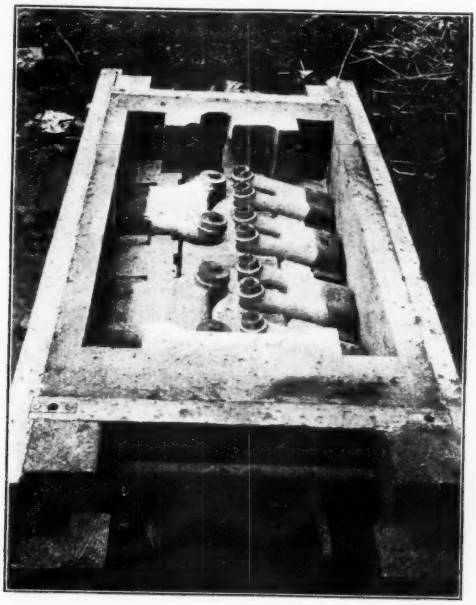

Fig. 24.

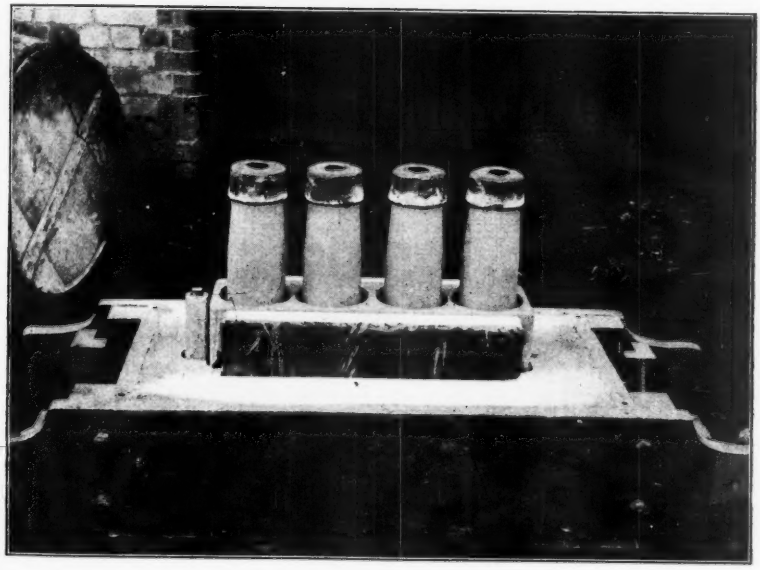

Fig. 25.

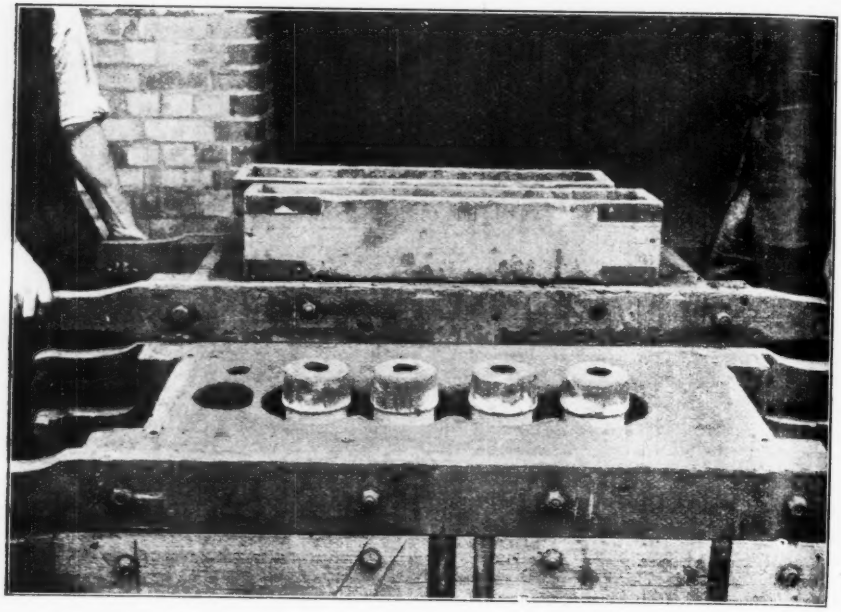

Fig. 26.

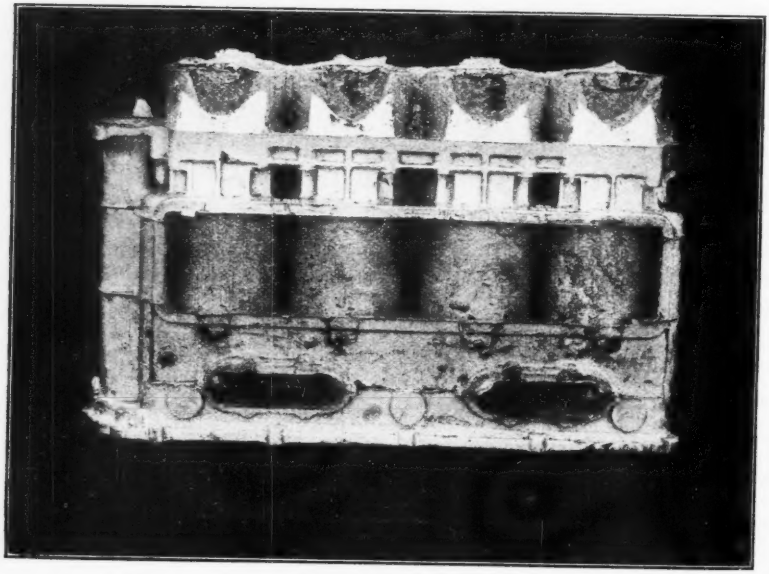

Fig. 27.

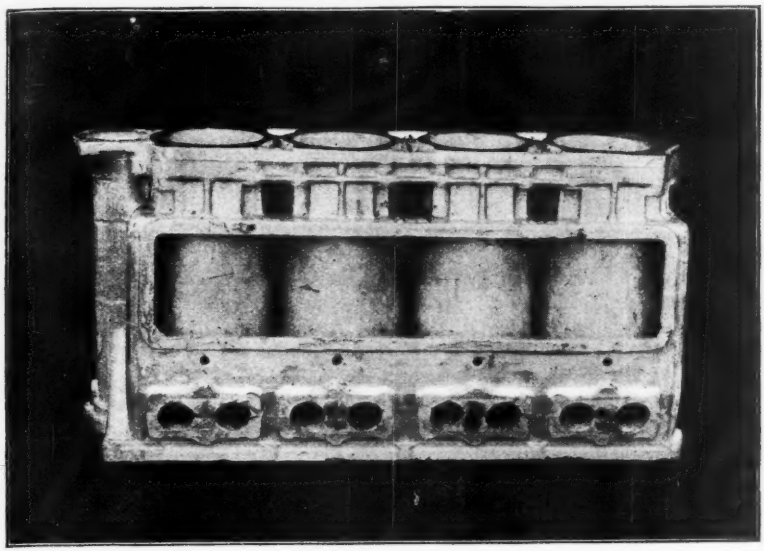

Fig. 28.

Let it be assumed that a force P, Figure 29, is acting on a boss at a distance from a vertical rectangular section ABCD on XX. Then if the boss and the plate bend together, the deflection at the end of the cantilever of length x must be the

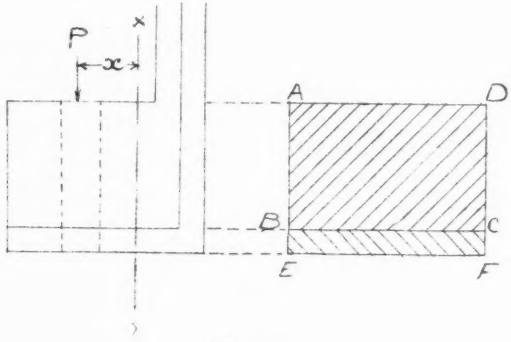

Fig. 29.

same in the steel and aluminium. Let P_a be the load taken by the aluminium and P_s that taken by the steel. Then :—

$$P_a + P_s = P$$

and if the steel and aluminium deflect together

$$P_a x^3 / 3E_a I_a = P_s x^3 / 3E_s I_s$$

I_a being the moment of inertia of ABCD and I_s of EDCF, while E_a and E_s are the moduli of elasticity of the aluminium and steel respectively.

Therefore,

$$P_0/P_1 = E_a I_a / E_s I_s$$

Now

$$E_a/E_s = \tfrac{1}{3} \text{ about}$$

Therefore,

$$P_0/P_1 = \tfrac{1}{3}\, T^3/t^3$$

If

$$T = 5t$$

Then

$$P_0 = 41.6\, P_1$$

and if

$$T_0 = 10t \quad P_0 = 333\, P_1.$$

So that the aluminium must carry nearly all the load unless made much thinner than in the Sunbeam engine, or if the flange of the liner is to give any material assistance it must be made thicker than it was made in the Sunbeam engine.

The Sunbeam Maori Engine is very similar to the Sunbeam Arab, except that the cylinder block has three instead of four cylinders.

Liners in Aluminium Cylinders

As already stated, liners in cast iron and mild steel have been used with success in aluminium cylinders, and at the R.A.E. a phosphor bronze liner was tested and found to be satisfactory. Attempts have also been made to deposit liners electrically in aluminium cylinders. Further research is, however, required in this direction.

Incidentally, it is of interest to note that an engine with an aluminium alloy cylinder has been run without a liner, for some hours, quite successfully. Alloys have not, however, been developed that could confidently be used without liners under every-day working conditions. One reason is, I think, that the alloys of aluminium have a high coefficient of friction and, when used as bearings, only comparatively small bearing loads can be allowed without risk of seizure.

In the B.H.P. Puma engine and in the Hispano Suiza engine, the liners are screwed into the cylinder. In the Sunbeam Arab engine and Bentley rotary engine, and in the air cooled engine (Fig. 1) that was put forward by the R.A.E. and which successfully passed its tests, the liners are plain cylinders. In all these cases, except the Hispano Suiza, the liners are made larger in diameter than the cylinder, or are given what is called negative clearance, and the aluminium cylinder is heated to a sufficiently high temperature to allow the liner to be easily screwed or dropped into the cylinder. The amount of negative clearance that should be given is very important from two points of view :—

1. The negative clearance should, if possible, be sufficiently large, so that when the cylinder becomes hot the cylinder shall remain in contact with the aluminium without becoming overheated.

2. On the other hand, if the negative clearance is made too large, there is a considerable risk of cracking the aluminium cylinders when they are shrunk on to the liners.

In this connection it should not be overlooked that when a hot body such as the aluminium cylinder shrinks on to the cold liner thermal stresses of rather unknown quantity, but which may be by no means negligible, may be set up.

Before passing on to consider in detail what negative clearances are desirable when the liners are put in, it may be desirable to consider briefly the probable temperatures that cylinder walls will reach under working conditions. Dr. Gibson has carried out a very considerable number of tests to determine the temperatures reached in the walls of a cylinder. For example :—

Air cooled single cylinder engines having 100 m.m. diameter bore and a stroke on 140 m.m. were run at 1,800 revolutions per minute in a 60 miles wind.

Cylinders of

(A) Aluminium alloys containing
(1) 7% copper.
1% tin.
1% zinc.
(2) 9% copper.
2% nickel.

(B) Cast iron

were tested. The aluminium alloy cylinders were fitted with steel liners. The compression ratio was 4.7 in all cases; the maximum M.E.P. of 115lbs. per sq. inch was obtained from the cylinders 1 and 2. The petrol consumption in case 2 was 6% higher than in case 1. At present we are not concerned with the 6% excess of petrol consumption, as that may or may not have been due to the change in the alloy. The mean temperature of the barrel of both aluminium cylinders was about the same, but the maximum temperature of 2 was greater than the maximum of 1, while the minimum temperature of 2 was less than the minimum temperature of 1. The temperature of the liner was in parts as much as 26° C. hotter than the cylinder. The maximum temperature recorded was 233°C. on the leeward side of the cylinder near the top of the combustion space. The maximum difference of temperature between the front and back of the cylinder was, in a number of tests not greater than 63°C., and the maximum difference between top and bottom of the cylinder was 68°C.

From tests on the water cooled Hispano Suiza engine Dr. Gibson has also shown that in one cylinder during the test, two plugs being used, the temperature of the liner 1in. below the upper surface of the piston was as high as 241° C., and at 3.3in. below the upper surface of the piston 191°. In another test, using one plug, the temperature of these points was 172° C. and 137° C. respectively. In another cylinder the same plug was used, and the corresponding temperatures were 182° C. and 138° C. and 144° C. and 114° C. respectively. When we come to the question of the burning pistons it will be seen that there is *prima facie* evidence that even higher temperatures than those recorded by Dr. Gibson are probable.

Incidentally, it is of interest to note that in the hottest cylinder the difference of temperature between the cooling water and some parts of the liner was 180° C.

The difference of temperature between the cylinder and the liner is undoubtedly very largely affected by the slackness or tightness of the liner, and on the accuracy of the workmanship. Slight eccentricities or lack of parallelism of the two may make considerable differences. If the liner is put into the cylinder with too small a negative clearance it will heat up under working conditions until it comes into contact with the cylinder, or else it will expand until the amount of contact, or the air gap, is just sufficient to transfer the heat across with a certain difference of temperature. It seems probable that in the case of the Hispano Suiza engine, in which the liners were screwed into the cold jackets, the liner was much hotter than in the R.A.E. or the Sunbeam engine, and may have been a contributory, if not the main, cause of the trouble due to burnt pistons experienced at one time in connection with this engine.

Assuming the liner and the aluminium to be just in contact at 15° C., and also to be just in contact when the aluminium is heated through 150° C., or is at a mean temperature of 165° C., then, neglecting the stresses due to internal gas pressure, the mean temperature t of the liner would require to be higher than that of the aluminium. The expansion of the aluminium will be $26 \times 10^{-6} \times 150d$, and of the steel $10 \times 10^{-6} \times (t-15)d$. For contact these must be equal, and thus t equals 390° C. If, however, there were perfect metallic contact between

the liner and the aluminium it would hardly be possible for this condition to exist, and probably what would take place, therefore, would be that the liner would expand in relation to the aluminium to give such metallic contact, or leave such an air gap, as would allow a steep heat gradient between the liner and the cylinder wall. If now the liner is put into the cylinder with negative clearance the difference of temperature between the liner and aluminium can be very considerably reduced.

Let d be the outside diameter of the liner when at 15° C., and d_1 the internal diameter of the aluminium cylinder. The negative clearance c is then $d-d_1$. Let E be the modulus of elasticity of steel and E_a that of the aluminium. Let it be supposed that the liner and the aluminium are to be at 150° C. when under working conditions, except that stresses due to gas pressures are neglected. When the liner is inserted the aluminium jacket will have to be heated to some temperature to allow the liner to drop into the cylinder. When the jacket cools it will contract and will be stressed in tension while the liner will be in compression. Let the compressive stress in the liner when cold be p tons per sq. inch. Let t be the thickness of the liner and T of the aluminium, then the stress in the aluminium is

$$f = pt/T$$

The diameter of the liner when cold will be approximately

$$d - pd/E \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and the diameter of the aluminium cylinder will be approximately

$$d_1 + fd_1/E_a \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

equating (1) and (2)

$$fd_1/E_a + pd/E = d - d_1.$$

Let $E/E_a = m$, then since d and d_1 are nearly equal,

$$f = (d-d_1)/d \; . \; E_a mT/(mt+T)$$

Let $T/t = 4$

$E_a = 4{,}500$ tons per sq. inch and $m = 3$.

Then assuming Hookes' law to hold, $f = 3.3$ tons per sq. inch. This would probably be higher than the elastic limit of the alloy, in which case the actual stress produced would be slightly less than 3.3 tons per sq. inch; on contraction a small permanent set may be given to the aluminium cylinder. Lieutenant-Colonel Jenkin has treated this subject at greater length in an interesting paper communicated to the Light Alloys Sub-Committee.

A number of cylinders have been found cracked after the liners were inserted; it has not been easy, however, to trace the exact cause of the cracking. Contraction stresses, unequal stresses on cooling, and thermal stresses are, no doubt, important, and in some cases foundry defects develop or are discovered after the liners are inserted and the shrinking on may be blamed; hard cores particularly have no doubt been responsible for cracked cylinder barrels. Unequal thicknesses and walls being too thin have also probably had something to do with the cracking, but it would appear from the above calculation that if the walls of the cylinder are less than three times the thickness of the liner considerable stresses may be set up. The stress is also proportional to the negative clearance, and this should not be much more than 1/500th of the diameter of the cylinder; the jacket should then be heated to 120° C. or more to allow the cold liner to drop in easily. Care should be taken in inserting the liners that the cylinders are not exposed to cold draughts, which cause unequal cooling and risk of fracture. Messrs. Siddeley Deasy and Messrs. G. and J. Weir adopted a special furnace, the cover of which could be easily removed, and the liners could be inserted in the jackets without removing the jackets from the furnace.

The very different coefficient of expansion of aluminium and steel or cast iron sometimes makes it necessary, when the cylinder and the liner have become cold, to force home the liner by hydraulic or other pressure. For example, in the B.R.2 engine the liner has a flange at the upper end on which the valve port head makes a metallic joint When the cylinder cools, after inserting the liner, due to the relative contraction, a gap is left between the flange and the aluminium, and pressure is thus required to force home the liner. In such cases the maximum pressure should be carefully controlled.

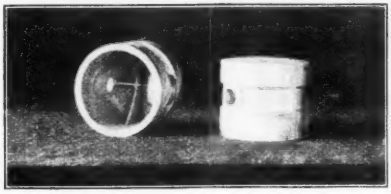

Fig. 30.

Aluminium Pistons

A very considerable number of types of aluminium pistons have been developed. Typical examples of these are shown in Figures 30 to 35; some of the pistons shown in Figure 32 have been cut and one piston is shown which was burnt in the engine. On comparing the pistons in Figure 32 it will be seen that in most of them the gudgeon pin bosses are carried on the skirt of the piston, the exception in this figure being the B.R.1 piston, which has its gudgeon pin bosses carried direct from the crown. In Figure 34 is shown the Dragon Fly piston, which again has its bosses carried on ribs directly attached to the crown. The

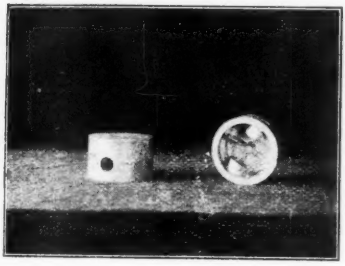

Fig. 31

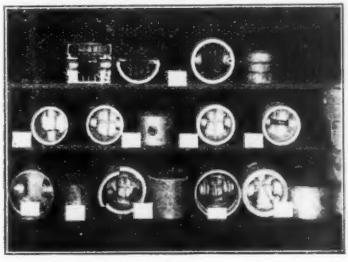

Fig. 32.

Hispano Suiza piston, as shown at the top of Figure 32, is an example of a heavily ribbed piston. It is generally claimed that ribs assist in the cooling of the piston by transmitting heat to the air in the crank case. The heat balance sheet of an engine, however, shows that the total amount of heat carried away to the crank case is comparatively small, and, therefore, if the ribs are effective from the point of view of conducting heat from the crown to the skirt they are not effective in conveying heat from the crown to the air in the crank case. Ribs may be required to strengthen the crown of the piston, especially in pistons of greater diameter than 4in., but it is very doubtful whether a large number of ribs, such as are used in the Hispano piston, are of any value; one, must, however, have an open mind upon this question; ribs certainly add to the difficulty of casting. The original sand cast pistons of the Sunbeam Arab engine had six ribs; by making

four ribs instead of six, Fig. 31, it was found possible to cast these pistons easily in the die, and running tests showed that the four-rib piston had no disadvantages as compared with the six-rib.

For pistons up to 4in. diameter a ribless piston with a dome-like crown thickened towards the skirt and with a good fillet where the crown and skirt join is all that is required, and even for larger diameters it seems more than probable that such a construction would prove satisfactory. Experiments at the R.A.E. have shown that such a piston runs cooler than a piston of the same weight with ribs.

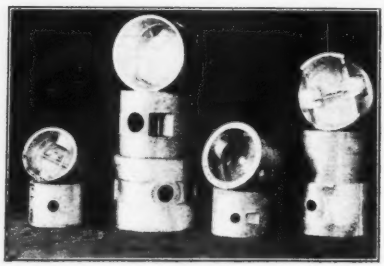

Fig. 33.

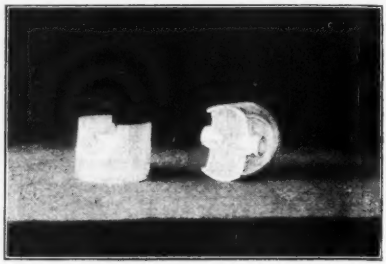

Fig. 34.

The Negative Clearance to be Given to Aluminium Pistons

Experience has shown that when aluminium pistons are required to work in cast iron or steel liners a comparatively large clearance is required between the piston and the liner when cold. The reason for this was not at first sufficiently clearly recognised, and when seizures took place they were not infrequently wrongly said to be due to growth in the aluminium. Growth does take place to a small extent in alumnium when it is heated to a temperature of 260° or more, but the possible growth is small as compared with probable relative expansion that may take place between the piston and the liner. There seems no doubt that the large coefficient of expansion of aluminium alloys as compared with that of steel and cast iron, and also the possibility of distortion at high temperatures are of greater importance than actual growth. It will be seen later that the

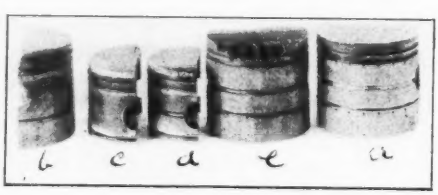

Fig. 35.

possible relative expansion of a piston 120 m.m. diameter (4.7in) may be as large as 20 mils, whereas the growth of such a piston is never likely to be more than 5 mils, and may be much less.

By annealing pistons made of various alloys at temperatures varying from 200° C. to 410° C., for varying periods of time, we found that the growth of a 4in. piston never exceeded 3.2 mils. When annealed at 410° C. the pistons distorted considerably more than they grew, the maximum distortion recorded being 16 mils.

Experiments at the R.A.E. showed that under running conditions the growth of a 4in. diameter R.A.E. piston ceased after 30 hours running, and in a piston made of alloy containing 7% copper, 1% tin and 1% zinc, the growth after 40 hours was only .002in.

Another piston containing 14% copper and 1% manganese grew .0044in. in 55 hours.

Table 1 shows results of a series of test measurements taken from a number of R.A.E. pistons, 4 inches diameter. These were carefully measured, heated at 340° to 360° C., measured, then heated again, and so on. It will be seen that even at this rather high temperature, growths and distortions are very small indeed after the third heating.

Dr. Shakespeare, at Birmingham, very elegantly showed how the coefficient of expansion of aluminium alloys changes with temperature, and also showed that if the alloy is annealed at 260° C. for about four hours it grows rapidly for the first two hours, but after four hours the growth is very small indeed. If curves are plotted showing growth with time the curve becomes nearly parallel to the axis of time after about five hours heating. The mean coefficient of expansion for the aluminium alloys is of the order of 26×10^{-6}. It may, therefore, be definitely taken as proved that distortion is likely to be more important than growth in causing seizing, but the most important factor of all is probably the relative expansion of the piston and the liner, which may be as great as from 4 to 6/1,000ths per inch diameter.

Dr. Gibson has found that the maximum recorded temperature in a piston 100 m.m. diameter, having a stroke of 140 m.m., in an air cooled engine, measured within ten seconds of shutting off the petrol supply, was 240° C. while the liner was at a mean temperature of 145° C.

In the tests of a Hispano Suiza engine much higher temperatures of the liner were reached and the difference of temperature between the pistons and parts of the liner was in a certain case as much as 85° C. It would appear, therefore, that the difference of temperature between the piston and some parts of the liner may be nearly 100° C. Incidentally, it may be mentioned that in the same air cooled engine, in which the maximum temperature of the aluminium alloy piston was 240° C., the maximum temperature recorded on a cast iron piston was over 400° C., while that of the liner was 145° C.

Let the liner be assumed at a temperature of $t°$ C., and the piston at a temperature of $(100 + t)°$ C., and let d be the diameter of the piston when at 0 deg. Centigrade, and d_1 the diameter of the cylinder. As a first approximation for the purpose of this calculation, d and d_1 may be taken as being equal. Taking the coefficient of expansion of aluminium as 26×10^{-6} and of steel and cast iron as 10×10^{-6}, the relative expansion of the aluminium and the steel liner will be

$$e = \{ (100 + t)\ 26 - 10t \}\ 10^{-6} d$$

or

$$e = (2{,}600 + 16t)\ 10^{-6} d$$

If t equals 150° C. then $e = 50 \times 10^{-4} d$. If d equals 120 m.m. (4.7 inches) then $e = 23.5 \times 10^{-3}$, which is very much greater than any possible growth. Allowing 3 mils for growth, the piston ought not to have, under these conditions, less than 27 mils clearance, and if distortion is likely to take place the clearance ought not to be less than 30 mils.

If the difference of temperature between the piston and the liner of 50° C., and the liner at 150° C., then $e = 17.4 \times 10^{-3}$; a minimum clearance of 24 mils will probably be required.

The piston will always be hotter at the crown than at the skirt, and the clearance at the crown should thus be greater than at the skirt. On the other hand, clearance at the crown should not be too large, as there is a danger of the deposit of a layer of solid carbon.

TABLE I.

GROWTH OF ALUMINIUM PISTONS.

Piston No.	Composition.	Growth where Turned.								Growth.
2	14% Cu 1% Mn Sand Cast not prev. heated.	Turned on crown and skirt only.	Heated for five hours between 340 and 360° C.	Crown	Skirt	A .0047 B .0033 C .0018	Turned short distance inside skirt and all over outside.	Heated for five hours between 340 and 360° C	Crown	Skirt	A — .0049 B — .0022 C — .0029	Heated for five hours at 340° to 360° C.	— .0001 — .0003 + .0000
				Crown	Skirt	D .0035 E .0033 F .0038			Crown	Skirt	A — .0030 B — .0033 C — .0032		— .0002 — .0001 — .0002
5	12% Cu Chill Cast prev. heated to 410° C. for five hours.	do.	do.	Crown	Skirt	A .0076 B — .0034 C — .0033	do.	do.	Crown	Skirt	A — .0007 B — .0027 C — .0012	do.	+ .0016 + .0012 + .0006
				Crown	Skirt	D .0010 E — .0002 F — .0001			Crown	Skirt	A — .0008 B — .0012 C — .0012		+ .0004 + .0003 + .0007
9	12% Cu 2% Sn 1% Mn Chill Cast not prev. heated.	do.	do.	Crown	Skirt	A .0041 B — .0013 C — .0018	do.	do.	Crown	Skirt	A — .0001 B — .0002 C .0003	do.	— .0005 — .0006 — .0003
				Crown	Skirt	D .0010 E .0006 F .006			Crown	Skirt	A .0005 B .0006 C .0007		— .0013 — .0012 — .0012
15	14% Cu 1% Mn Chill Cast prev. heated to 410° C for five hours.	do.	do.	Crown	Skirt	A .0035 B — .0016 C — .0018	do.	do.	Crown	Skirt	A — .0004 B — .0004 C — .0002	do.	— .0005 — .0006 — .0007
				Crown	Skirt	D .0004 E .0000 F .0000			Crown	Skirt	A — .0002 B — .0001 C + .0001		— .0006 — .0009 — .0010
22	14% Cu 1% Mn Spec.Chilled not prev. heated.			Crown	Skirt		do.	do.	Crown	Skirt	A .0028 B .0008 C .0012	do.	.0000 — .0002 — .0002
				Crown	Skirt				Crown	Skirt	A .0026 B .0023 C .0024		— .0005 — .0003 — .0007

The diameters A and D were taken in the line of the gudgeon pin. The diameters B and C were at 60 degrees to this line. The results indicate that the positive growth cannot be serious, and that after the first growth distortions may take place. If these are removed the pistons can be heated for further periods without distortion or growth.

The "Burning" of Aluminium Pistons

From time to time, and particularly during the rather severe test to which engines are subjected before being sent away from the works, what might be called epidemics of piston "burning" have been met with. For example, in connection with one type of engine very little trouble had been experienced from this until about December, 1917, when suddenly it was found that after the two hours' test and engines were stripped down the crowns of the pistons taken from some of the cylinders were found to be badly "burnt." This in its first stages consists of a slight pitting of the surface of the crown of the piston, as shown by the example on the table and in Figure 35. When carried further the small pits deepen, and finally part of the crown of the piston may be entirely burnt away, as shown to the right of the figure.

On carefully examining the badly burnt piston it will be seen that the surface has a distinct columnar structure, which suggests that softer parts of the alloy have been drawn from round about the harder columns. This "burning" of

Fig. 36.

the piston, which is not to be confused with cracks in pistons through which the hot gases may penetrate and soon wear a hole in the piston, appeared to commence in nearly all cases near the circumference of the crown, or, in other words, at the junction between the crown and the skirt, and to spread inwards towards the centre. On taking an engine down, containing eight pistons, it would probably be found that two, three or more pistons were "burnt," but all the pistons would not be burnt, and of those that were the burning would not be at any particular part of the crown, relative to, say, the inlet or exhaust ports. It was therefore impossible to relate the phenomenon to any particular condition obtaining relative to the incoming or outgoing gases, and furthermore, since it might occur in any one of the cylinders of the eight cylinders of the engine, it was found impossible to relate it to the water circulating system. A change in the character of the spirit used in the engine did not appear to make any difference in the number of the pistons burnt, and changes in the temperature of the cooling water did not affect the problem to any considerable extent. There seemed no doubt that in some way or other the phenomenon must be due to an excessive temperature reached in the piston, or else it must be due to a particular condition

of the material of certain pistons, which allowed of the peculiar kind of disintegration to take place, to which we have already referred.

Now the temperature reached by the piston will no doubt depend largely upon the power produced in each cylinder and the facility with which heat can escape through the piston to the walls of the cylinder, and if the engine is to run for any considerable time at the full power produced, the temperature reached might be such as would endanger the piston. The specification for testing the engine, from which the pistons shown in Fig. 35 were taken, required that the engine should be run for at least two hours, of which the last five minutes should

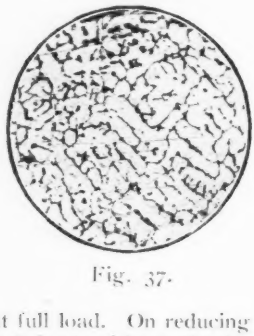

Fig. 37.

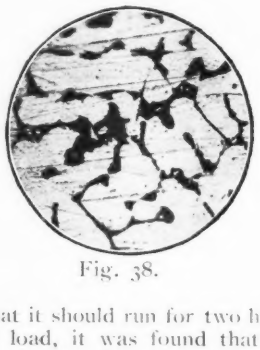

Fig. 38.

be at full load. On reducing this specification so that it should run for two hours on 0.8 load without the last five minutes at full load, it was found that the "burning" very considerably diminished. Further, reports from the squadrons showed that in this engine the phenomenon of "burnt" pistons was very infrequent in the air, which again appeared to indicate that the test load was too severe for the engine and was very largely responsible for the number of pistons found to be "burnt" on stripping down the engines after the test. This, of course, was *prima facie* evidence that in certain conditions of running tempera-

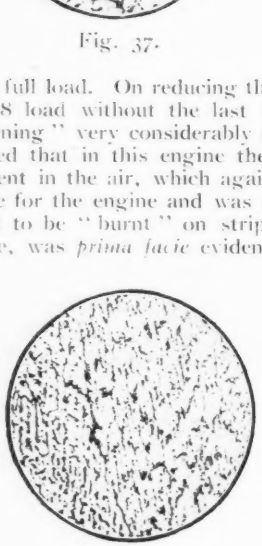

Fig. 39.

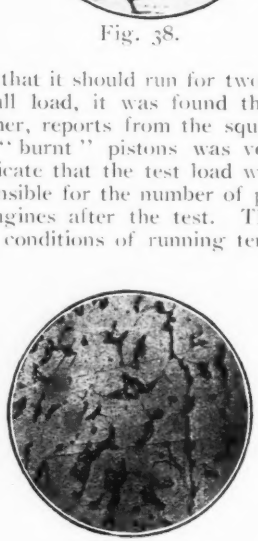

Fig. 40.

tures were reached which were greater than the alloy could reasonably withstand, but it did not suggest what this temperature was. It therefore became important to try and determine at what temperature it was possible for the pitting to occur, and to inquire into the possibility of the structure of the material in the piston being a contributory cause of the failure. If some lower limit of temperature could be fixed at which the phenomenon could take place, or if it could be shown that the phenomenon occurred only in those pistons, the metal of which had a particular structure, it would then be possible to overcome the difficulty, either by taking care that the temperature in the cylinder should not reach its lower limit, or possibly by a new method of casting the pistons. A careful examination

was made of the very large number of pistons, and although at one time it seemed to be indicated that pistons having a particular structure, which they appeared to have when die cast at an excessively high temperature of 850° C., were much more likely to fail than others cast at a lower temperature and which had a finer structure, it was found impossible finally to prove that any particular structure of piston was of necessity primarily responsible for the "burning" of the piston. It is interesting to note, however, that on examining the alloys under the microscope it was found that the material near the surface of the crown showed a distinct columnar structure.

Mr. Kipling, of the Wolseley Motors, Ltd., found that in pistons that had been cast at a high temperature in a chill, and had been burnt on test, the columnar structure of dendrites or columns of pure aluminium surrounded by sheaths of eutectic, which has a low melting point, could be seen with the naked eye. In some of the pistons examined these columnar crystals were found to be of considerable length. Mr. Kipling suggested that only those pistons which showed this columnar structure near to the crown gave evidence of "burning." Further investigation by my assistant, Mr. Wills, showed, however, that pistons which did not exhibit this columnar structure near to the crown to the naked eye were burnt in the engine. Again, certain pistons which ran 100 hours in the engine, although perhaps not quite at full load, certainly did exhibit under the microscope, although not to the naked eye, a distinct columnar structure near to the crown. Figure 36 shows a section taken perpendicular to the crown of the piston near to the part where "burning" had taken place. It will be seen in this case that the crystalline structure, multiplication 60, shows the columnar habit with the axes of the columns running perpendicular to the surface. This columnar structure, however, is not visible to the naked eye. Figure 37 shows a section taken near the surface of the piston. This piston had been very slightly "burnt" during running. Near to the surface, under the microscope, small holes can be seen in the casting, from which the eutectic has been exuded. Figure 38 shows the same section to a larger scale. The $CuAl_2$, which is shown in the black masses, has, however, not been in any way affected, showing that its temperature had been less than 540° C., and a small distance below the surface the alloy certainly had not been above 540° C., as will be seen by comparing Figure 38 with Figures 39 and 40 which are taken from a piece of piston annealed above 540° C. In Figures 39 and 40 the black masses have become duplex in structure, which is characteristic of a chilled alloy after annealing at a temperature above 540° C.

Mr. L. J. Wills, M.A., who was my assistant at Birmingham and to whom I am indebted for the very excellent microphotographs, endeavoured to reproduce the conditions found in these pistons artificially by playing upon the surface of a piston with the oxy-acetylene blow pipe.

Figure 41 shows the effect produced by the oxy-acetylene blow pipe playing on a piece of annealed aluminium. The inner face of the crown was kept cool by air or steam. It will be seen that the exudation is blotchy, and differs very markedly from the nature of the exudation in Figure 42. The exudation in Figure 42 when removed leaves little pits very similar to those found in the "burning" pistons. Now photograph 42 shows the surface of the aluminium on which the blow pipe has been playing, after the metal had been annealed for some hours at a temperature above 250° C. Specimens were annealed at from 250° to 260° C., and others at 400°, 450° and 500° C. respectively, and heated with the blow pipes; in all these the globular type of eutectic was exuded similar to that of Figure 42, whereas when the blow pipe was played upon the specimen before annealing, the blotchy type of exudation, Figure 41, always occurred. When the oxy-acetylene flame was played on to a piston that had been rejected because of local "burning," the eutectic exuded in the globular form. Figure 43 shows a globule of eutectic just caught in the act of exuding from the surface (multiplication 60). Figure 44 shows a section (350 diameters) taken through the eutectic

globule, and exhibits the beautiful eutectic structure consisting of alternate white layers of aluminium and the black layers of $CuAl_2$. It would appear, therefore, that the globular exudations, which are characteristic of what we call "burnt" pistons, only occur after the pistons have been heated for some time at a temperature from 250° C. and are afterwards heated to a temperature high enough to soften this eutectic sufficiently to cause it to be exuded. Figures 45 to 47 are taken from a piston which had seized and in which the temperature apparently had been sufficiently high to allow of the formation of the duplex eutectic, and a considerable amount of it had escaped from the surface. Photograph 46

Fig. 41.

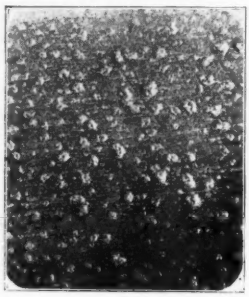

Fig. 42.

especially shows this. Photograph 47 shows the characteristic condition, magnification of 1,000, of the material, after heating at 540° C.

Now it is well known that at temperatures even below 400° C. aluminium alloys become very soft, and at a temperature of 540° C. the eutectic, surrounding the crystals of aluminium, melts. Cooling curves for aluminium copper alloys are shown in Figure 48. If, therefore, the surface of the piston reaches a temperature of 540° C. the eutectic will certainly be forced out of the piston. Mr. Wills' experiments showed clearly the possibility of the surface temperature being sufficiently high for the eutectic to be exuded without pressure, while the mean temperature of the piston is very far below 500° C. That pistons which have

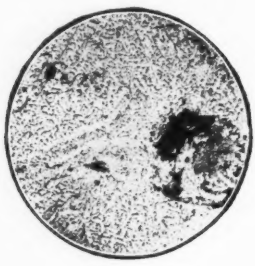

Fig. 43.

Fig. 44.

burnt have a mean temperature of the crown far below 500° C. is shown by the fact that burning takes place without the slightest sign of distortion in the piston. Further, as already remarked, the highest temperature recorded by Dr. Gibson in a piston, 10 seconds after stopping the engine, was 275° C. In this case, however, there was no sign of burning, and the conditions were evidently not so severe as in

the engines where burning had occurred. A consideration of the laws of conductivity of heat suggests the impossibility of the mean temperature of the surface being very much greater than the mean temperature of the piston, and the mean temperature can hardly be greater than 400° C. without considerable distortion. If, therefore, burning only takes place when the temperature approaches the melting point of the eutectic this temperature must be very local, and conditions must obtain in the engine similar to what takes place when an oxy-acetylene blow pipe plays on the surface of metal. There are grave objections to this theory

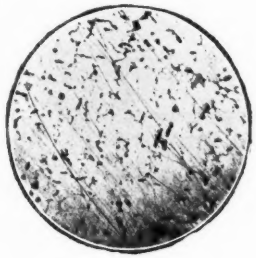

Fig. 45.

Fig. 46.

and further experiments have clearly shown that the surface temperature cannot be more than a few degrees hotter than the centre of the crown; it may be, therefore, although it is difficult to see how it can be so, that the eutectic is exuded by mechanical action at temperatures below the melting point of the eutectic.

In the engine this intense local heating may be due to local high temperatures in the gases, which is difficult to conceive, or due to local seizure, or, what is probably more likely, due to the local overheating of the liner. Dr. Gibson has shown that very different temperatures may exist in the liners of the various cylinders of an eight-cylinder engine, and as we have already remarked the liner of a cylinder may be very hot if good contact is not ensured between the liner and the jacket. In the particular engine to which we have referred the liners

Fig. 47.

were put into the cold jackets and, therefore, it might have been possible for the liner in some of the cylinders to become very hot. On the other hand, a careful examination of the liners failed to reveal any excessive "blueing," which would have been indicative of high temperatures. Pitting of the surface may take place at much lower temperatures than the melting point of the eutectic, but it probably does not take place at temperatures below 300° C. It is of interest to note that with certain alloys containing zinc we found small beads were squeezed out of the metal when determining Brinell hardness at temperatures a little above 300° C.

The evidence has certainly been very conflicting, and it is difficult to come to definite conclusions. I have, a long time ago, suggested that attempts should be made to produce the phenomenon under definitely known conditions. If this is done it will be possible to say definitely how it can be avoided. If, when the liner of an engine reaches a certain temperature, it is possible to prevent the piston "burning," or if it is impossible to obtain more than a certain power from a cylinder without this risk to the aluminium piston, or if it is consequent upon bad fitting or imperfectly cooled liners and, therefore, too high temperature, then something definite will be known. Up to the present the only method of inquiry has been the examination of pistons after the "act," but nothing has

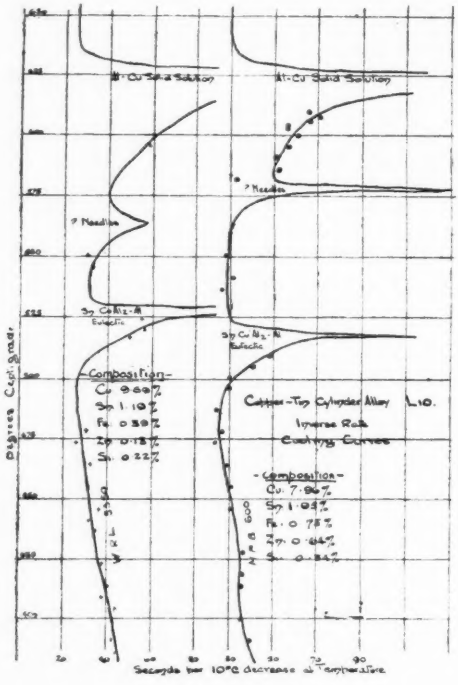

Fig. 48.

been known definitely of the conditions in the particular cylinder or cylinders, where the phenomenon has taken place. Unless this is obtained the remedy can hardly be found or the risk avoided with certainty. It may possibly be entirely overcome if alloys containing a small percentage of low melting point eutectic are used, but of this I am not very hopeful.

The Tensile Strength of Aluminium Alloys at Various Temperatures

It is important in considering the suitability of an alloy for pistons for aeroplane engines, that its behaviour at the temperatures at which it is likely to be working in the cylinder should be known, not only its ultimate strength but also the elastic limit should be determined. With this end in view we have carried out a number of tests at Birmingham and have investigated the properties of alloys of very varying compositions.

Figure 49 shows the ultimate strength obtained for alloys of the approximate compositions shown on the figure. It will be noticed that up to a temperature of 250° C. the tensile strengths of a number of these alloys may be very variable. At 350° alloys Nos. 1, 5, 6, 7 and 7a have approximately the same breaking strength. Alloys containing only 7% of copper are much weaker than the other alloys at all temperatures above 150° C. It will be noticed also that the chill castings at temperatures above 300° C. appear to have no advantages as far as strength is concerned over the sand castings. In Figure 50 are shown the breaking strength, the elongation per cent., the reduction in area, and the ultimate strength of the alloy containing 12% copper which has been so largely used for aeroplane

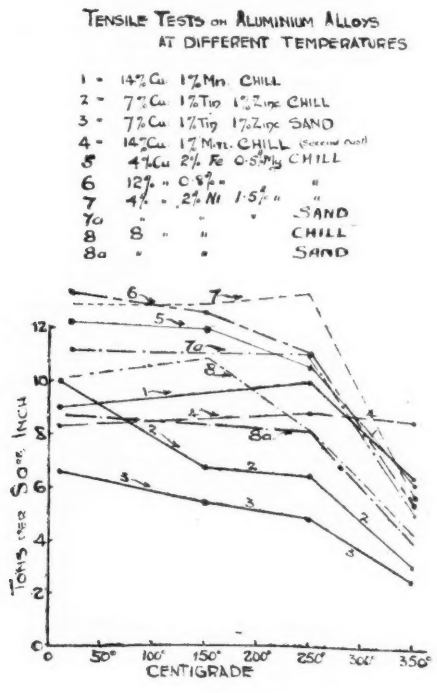
TENSILE TESTS ON ALUMINIUM ALLOYS
AT DIFFERENT TEMPERATURES
1 - 14% Cu 1% Mn CHILL
2 - 7% Cu 1% Tin 1% Zinc CHILL
3 - 7% Cu 1% Tin 1% Zinc SAND
4 - 14% Cu 1% Mn CHILL (Second cast)
5 4% Cu 2% Fe 0.5% Mg CHILL
6 12% " 0.8% " "
7 4% " 2% Ni 1.5% " "
7a " " " SAND
8 8 " " CHILL
8a " " SAND
TONS PER SQ. INCH
CENTIGRADE
0
50°
100°
150°
200°
250°
300°
350°

Fig. 49.

pistons; in these test pieces the iron content was somewhat higher than would generally be found, which no doubt increases the tensile strength at the higher temperatures.

Similar curves are shown for two other alloys in Figures 49, 50a and 51. On comparing these curves it will be seen that magnesium appears to have a considerable effect in raising the elastic limit up to a temperature of 250° C. The elongation per cent. is very much less than in some of the other alloys, or in other words the addition of magnesium apparently makes the alloys brittle. It is interesting to note that in all cases the elongation per cent. varies very little up to a temperature of 250° C. and then increases rapidly. This corresponds to the temperature at which growth begins, but it is doubtful if there is any association between the two phenomena.

A general examination of the curves would indicate that the 4% copper with either nickel or iron together with magnesium varying from .5% to 1.5% would, as far as their physical properties are concerned, be quite as good as the 12% copper alloy. They may have one distinct advantage; both of these alloys are lighter than the 12% copper alloy, and it is just possible that since they contain a less amount of eutectic certain advantages may be obtained if the pistons become somewhat overheated. The Brinell number of the 12% Cu alloy at 300° C. is 33, while that of the 4% Cu, 2% Ni, 1½% Mg is 56.7. On the other hand, there are disadvantages in having to deal with such complicated alloys as the copper iron magnesium, or the copper nickel magnesium alloy as compared with the 12% copper alloy in ordinary foundry practice; this is referred to in another part of this paper.

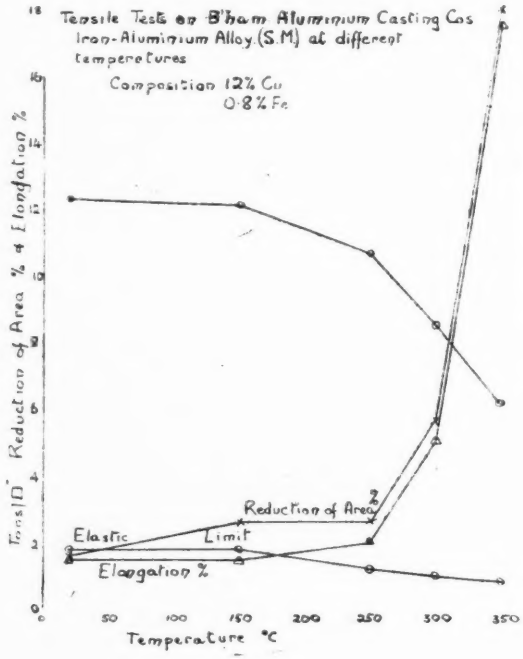

Fig. 50.

The alloys containing from 12 to 14% of copper and 1% of manganese are stronger at 250° C. than at ordinary temperatures. When sand cast the conductivity is low, but this is increased by annealing at 450° C.

Brinell Hardness Numbers at Various Temperatures on Aluminium Alloys

It has already been suggested that the breaking strength of an aluminium alloy at the temperature at which it is likely to be worked in the cylinder is not the only property that must be considered. It would appear that any changes in the hardness would indicate the liability of the piston to deform under the working pressure in the cylinders. It was, therefore, thought that if the Brinell numbers of the alloys that were suggested for aluminium pistons could be readily and clearly determined at temperatures from 50° C. to 400° C. the results would

probably give a reliable intimation as to the suitability of any given alloy for pistons and other parts subject to high working temperatures.

Experiments were therefore carried out in the hope that they would indicate a rapid and reliable method of judging the relative suitability of the various aluminium alloys for pistons and other engine parts subjected to high working temperatures.

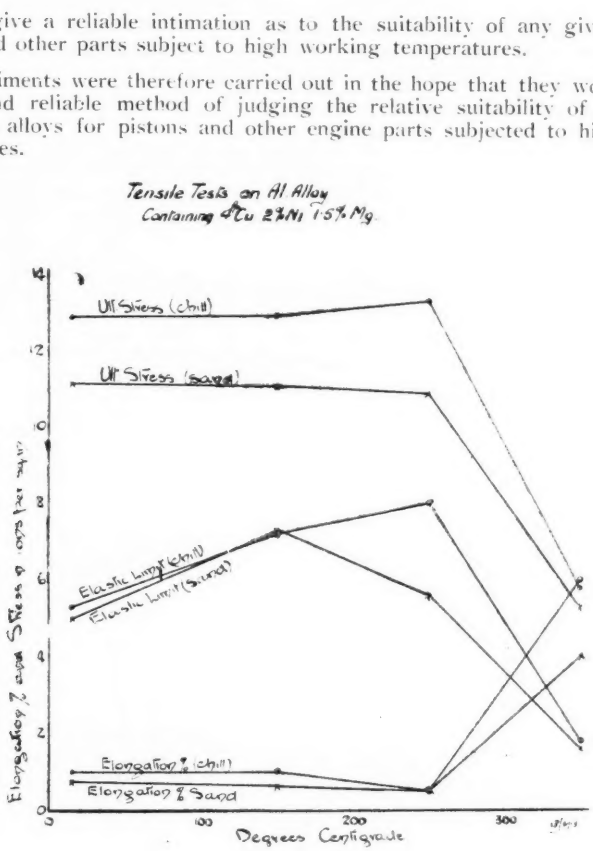

Fig. 50a.

The following alloys have been tested up to the present, both chill and sand cast :—

Specification.	Nominal Composition (per cent.).
L_5	13.5 Zn 2.75 Cu
L8	12.0 Cu
L10	10.0 Cu 1.25 Sn
L11	7.0 Cu 1.0 Sn 1.0 Zn
9 Cu 2 Sn 1½ Zn ...	9.0 Cu 2.0 Sn 1.5 Zn
4 Cu 2 Ni 1½ Mg ...	4.0 Cu 2.0 Ni 1.5 Mg

The tests have been carried out at 15, 150, 200, 300 and 400 degrees Centigrade.

Owing to the large variations which occur in these alloys the following precautions had to be taken :—

(*a*) All tests were made on specimens cut from 1in. diameter test bars in order that the results for the different alloys might be reasonably compared.

(*b*) In investigating the hardness of each particular alloy all the specimens tested were cut from the same bar. This eliminated as far as possible variations due to difference in composition and manufacture.

(*c*) In each alloy, wherever possible, two specimens were tested at each temperature, and the average of the figures thus obtained was taken as the hardness number. By this means it was possible to detect and discard low or erratic figures due to mechanical faults, such as small blow holes. Where these extra specimens were not available, however, the second impression had to be made on the reverse side of the specimen. Whenever this was done the fact has been noted in the accompanying table of results. It will be noticed that in most cases the duplicate figures thus obtained agree very well together.

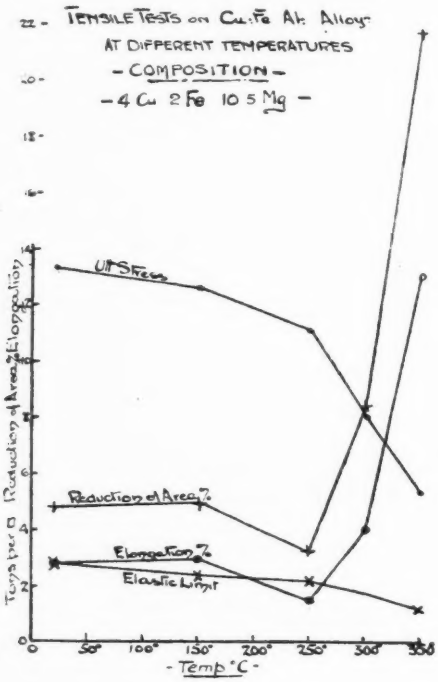

Fig. 51.

The specimens which, as stated above, were all cut from test bars were about 1in. diameter and $\frac{1}{4}$in. to $\frac{3}{8}$in. deep. The flat surfaces were polished to eliminate tool marks and scratches and thus facilitate the accurate measurement of the impressions.

The tests were carried out in a small electric furnace which had been specially designed by the author for use with one of the Brinell testing machines made by the firm of Aktiebol Alpha, of Stockholm.

The specimens to be tested were placed on the steel base of the electric furnace, which was then heated to the required temperature. This temperature, with a variation of not more than 2° C. in either direction, was maintained in every case for 8 to 12 minutes before the test was made, in order to make sure as

far as possible that the specimen was always uniformly heated throughout to the required temperature. As it usually took about five minutes to make a test, change the specimen, and bring the furnace back again to a steady condition, it was possible to test four specimens per hour when the furnace had once been heated up.

The temperatures were measured by an iron constantan thermo couple, the bare end of which was allowed to touch the specimen. The couple was connected to a direct reading instrument, on the scale of which every 10 degrees was marked and each degree could easily be estimated.

While the specimens were being heated the furnace was allowed to stand on a sheet of asbestos on the bench. As soon as they were ready the furnace, together with the asbestos sheet, was transferred to the table of the machine and the test made by bringing the steel ball in the machine into the depression on the top of a plunger in the furnace and loading this by means of the oil pump in the ordinary way. The pressure was thus transferred to the second steel ball attached to the bottom of the plunger. The ball which made the impression was, therefore, always in the furnace and at the same temperature as the specimen at the time of testing.

In every case a 10 m.m. diameter hardened steel ball was used with a load of 500 kilos., and the Brinell hardness number was calculated from the diameter of the resulting impression.

Preliminary experiments were carried out which showed that reliable results are obtained in tests at 15° C. when the load is applied for 10 seconds, and that if this period is increased there is no correspondingly uniform decrease in the diameter of the impression. As a result, however, of a few preliminary tests at 300° C. it seemed probable that the period of application of the load would be of considerable importance at higher temperatures.

To investigate this, therefore, a few tests were first made in which the loads were applied for periods varying from 10 to 70 seconds. The figures obtained are given in Table 2. It will be seen that the total variation in the hardness number is fairly small, while the variation due to an error of two or three seconds in the loading period is quite negligible.

TABLE 2.

BRINELL HARDNESS NUMBERS.

THE EFFECT OF DURATION OF LOAD AT 300° C.

Mark.	Specif.	10 secs.	30 secs.	60 secs.	70 secs.
HSP25	L10	27.1	28.8		24.5
	Chill	27.5	28.2	—	24.2
		27.8	27.6		23.8
WMCA	L11	28.2	26.5	24.9	
	Chill	27.6	26.0	25.2	—
		27.0	25.4	25.4	

In all subsequent tests, therefore, the load was applied for 10 seconds in every case.

The results are shown in Table 3.*

On the whole the higher the percentage of copper the harder is the alloy at all temperatures, irrespective of the other metals present in the alloys in small quantities. The four alloys which are highest in copper show

* Owing to printing difficulties, it was not found possible to reproduce curves plotted from results given in the Table.

TABLE 3.

BRINELL HARDNESS NUMBERS AT HIGH TEMPERATURES.

Mark.	Specif.	Actual Analysis.	500 Kilos Load. Brinell Hardness Numbers at 15° C.	150° C.	200° C.	300° C.	400° C.
HSP25 Chill	L10	9.72 Cu 1.25 Sn .61 Fe	62.8 61.8 } 62.2	—	48.9 *a*63.7 } 48.9	27.1 27.8 } 27.5	11.8 11.1 } 11.5
HSP35 Chill	L10	10.03 Cu 1.24 Sn .61 Fe	*b*62.2 *b*63.7 } 63.0	59.5 59.5 } 59.5	50.3 49.5 } 49.9	26.0 26.7 } 26.4	10.8 10.0 } 10.4
HSP8 Sand	L10	10.41 Cu	65.3 62.2 } 63.8	61.8 61.5 } 61.7	56.0 51.3 } 53.7	27.6 27.7 } 27.7	11.3 11.0 } 11.2
WMCA Chill	L11	7.61 Cu 1.50 Sn 1.46 Zn .74 Fe	60.2 59.5 } 59.8	58.7 58.7 } 58.7	47.6 44.8 } 46.2	28.2 27.0 } 27.6	12.7 11.6 } 12.2
WMSA Sand (*c*)	L11	6.95 Cu 1.45 Sn 1.66 Zn .58 Fe	56.0 53.2 } 54.6	54.9 52.0 } 53.5	41.5 45.0 } 43.3	24.8 25.1 } 25.0	11.1 10.4 } 10.8
M6	L5	3.01 Cu 13.01 Zn .61 Fe	59.5 63.7 } 61.6	43.0 40.7 } 41.9	32.1 38.0 } 35.1	16.5 14.9 } 15.7	—
L5 Sand (*c*)	L5	3.26 Cu 13.35 Zn .70 Fe	80.4 78.0 } 79.2	44.3 43.3 } 43.8	35.2 36.5 } 35.9	14.7 14.9 } 14.8	—
K6 Chill	L8	12.17 Cu .70 Fe	*b*80.4 *b*83.0 } 81.7	*b*70.8 *b*72.5 } 71.7	*b*63.7 *b*63.0 } 63.4	*b*33.8 *b*35.6 } 34.7	*b*13.5 *b*12.5 } 13.0
J5 Sand (*c*)	L8	12.13 Cu .69 Fe	*b*68.9 *b*65.0 } 67.0	69.0 69.0 } 69.0	59.0 56.7 } 57.9	*b*32.3 *b*34.0 } 33.2	*b*15.6 *b*13.1 } 14.4
H7 Chill	9 Cu 2 Sn 1½ Zn	9.32 Cu 2.15 Sn 1.42 Zn .50 Fe	61.8 62.6 } 62.2	61.0 54.5 } 57.8	47.1 49.1 } 48.1	27.4 26.0 } 26.7	9.7 10.0 } 9.8
G7 Sand (*c*)	9 Cu 2 Sn 1½ Zn	9.01 Cu 2.14 Sn 1.53 Zn .62 Fe	60.2 60.6 } 60.4	56.6 53.6 } 55.1	49.7 46.8 } 48.3	26.8 25.7 } 26.3	10.5 10.2 } 10.4
	Sand Chill	4 Cu 2 Ni 1½ Mg	4.00 Cu 2.12 Ni 1.56 Mg	71.3 76.2	— 73.2	61 67.6	45.7 52.7	17.2 —

NOTES.—(*a*) Figure discarded as obviously unreliable.
(*b*) Both impressions at the same temperature made on the same specimen, one on each side.
(*c*) Whole bar full of very minute blow or pin holes.

a considerable variation in hardness at 15° C., but these variations rapidly decrease as the temperature rises, until at about 400° C. there is very little difference between them.

L5, however, the high zinc alloy, though one of the hardest alloys tested at 15° C., loses its hardness with very great rapidity as the temperature increases. It will be noticed, moreover, that L5 seems to lose its hardness most rapidly in the first 150 degrees when compared with the alloys containing a higher percentage of copper.

Most of the sand cast bars tested, as noted in Table 3, showed the characteristic small pin holes or air holes that are often to be seen on the machined surfaces of cylinder blocks and other castings in these alloys. It is noticeable that in some cases the sand cast bars were harder than the chill cast bars in the same alloy.

One interesting phenomenon was noticed. When testing the alloys containing both zinc and tin small globules of metal were found on the polished surfaces of the impressions made at 300° and 400° C. These were probably minute globules of the zinc tin eutectic squeezed out of the alloy.

The relative hardnesses agree very well with the relative tensile strengths at temperatures higher than 200° C.; all the hardnesses tend to become nearly the same at 400° C. At 300° C. the Brinell hardness number of the nickel alloy is about double that of the 7% copper 1% tin alloy and is more than three times as great as that of an alloy containing 13% zinc and 3% copper.

A Benzŕ piston made by the Germans was found to contain a high percentage of zinc and copper, with 1½% of iron. This piston had a Brinell hardness of about 62 when cold, 28 at 300° C. and 11 at 400° C. Its tensile strength when cold was more than 13 tons per square inch. At 300° C. it was only 4.08 tons per square inch. It is therefore harder at 300° C. than L.11. There seems no doubt that the 1½% iron would considerably increase the strength at high temperatures and would probably raise the hardness at 300° C. so that at this temperature its hardness is practically equal to that of the 7% copper 1% tin alloy.

The results on the whole seem instructive. They clearly show the superiority of the high copper alloys (L8) over the high zinc alloy (L5) for all castings which are exposed to high temperatures, and that the effect of magnesium in hardening the alloys is very marked. The results, moreover, show sufficient uniformity to justify further similar tests on other alloys at present in use, and to warrant the assumption that such tests would rapidly give an indication of the resistance of any new alloy to high temperatures.

Elastic Limits of Aluminium Alloys and Their Behaviour Under Repetition Stresses

Aluminium alloys in aeroplane engine parts are subjected to rapidly changing stresses, and in many cases failure under repetition stresses has occurred. Crank cases have been found cracked, probably due to such stresses. It appeared desirable, therefore, to determine the ranges of stress, which under definitely known conditions would cause fracture, and to see if this range of stress was related to the elastic limit as determined by an ordinary extensometer. Ultimate tensile strengths and elastic limits are not always reliable as indicating the suitability of a material for a particular purpose; this is true of other metals as well as aluminium alloys.

The tests were carried out in a specially designed machine in which the test specimen is a rotating cantilever carrying a known weight at the end. The

† For analysis see Appendix.

shape of the specimen is so designed that it should break at a particular place, and where a specimen completed a test without breaking, the stresses were calculated at the point where fracture should have occurred. Owing, however, to imperfect machining or to lack of uniformity, some test bars did not break at the desired place and in that case the stresses were calculated at the actual point of fracture. All tests were carried out at an average of 4,000 revolutions per minute, and the stress in any outside fibre of the test bar thus varied from a maximum tensile stress to an equal maximum compressive stress, and back to the same maximum tensile stress 4,000 times in each minute. Vibration during the tests is hardly noticeable.

During the tests here recorded it was not found possible to run the specimen continuously until fracture occurred. Each test was therefore divided approximately into continuous running periods of about 9 to 10 hours followed by periods of rest of about 14 hours. During these periods when the machine was not running the weights were allowed to remain hanging on the specimen.

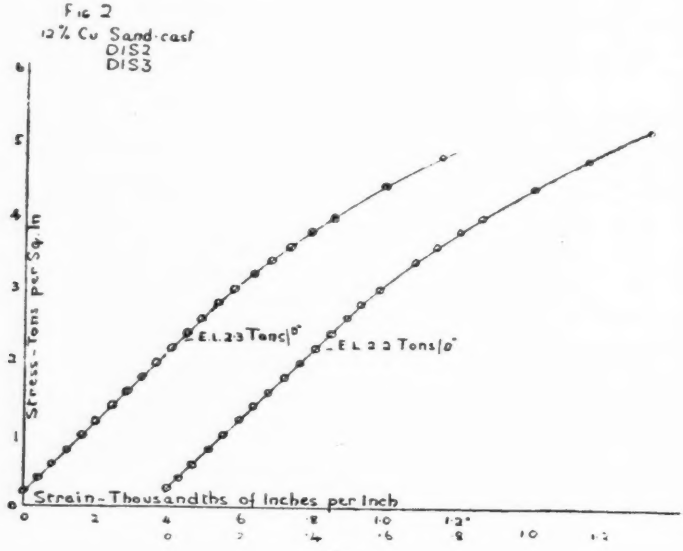

Fig. 52.

In order to ensure as far as possible a uniform composition throughout the whole series of tests here recorded, the bars for both the tensile and the Wohler tests were cast at the same time from the same pot of molten metal.

Repetition Tests on Aluminium Alloy (12 per cent. Cu.)

The stress strain curves obtained in the tensile tests are shown in Figures 52 and 53, and the results are also recorded in tabular form in Table 4. The strains were measured by a 2in. Ewing extensometer. It will be noticed that the small pin holes present in test bar D1C2 do not seem to have lowered the elastic limit, though they have appreciably affected the ultimate stress and elongation.

The results of the Wohler repetition stress tests are recorded in Table 5 and are shown plotted in Figure 54. It will be seen from Figure 54 that specimens which ran for one or more tests without breaking tended to give points slightly

above the line when they were finally broken. This is shown by specimens C1C2, C1S1 and C1S4. It should further be noticed that specimen C1S4 was allowed to run for over 15 millions at a stress not quite high enough to produce fracture, and was then allowed to rest for seven complete days before it was again tested

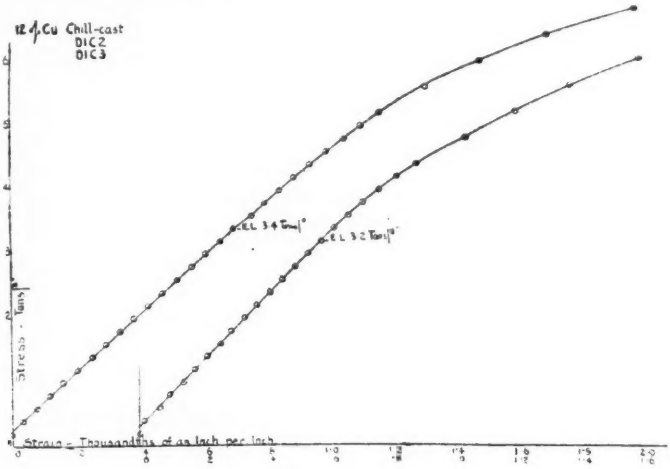

Fig. 53.

at a higher stress. As can be seen from the figure this point is well above the asymptote. This rather suggests that a large number of reversals at a low stress followed by a rest considerably improves the strength of this alloy, though this cannot be stated definitely without further exhaustive experiments.

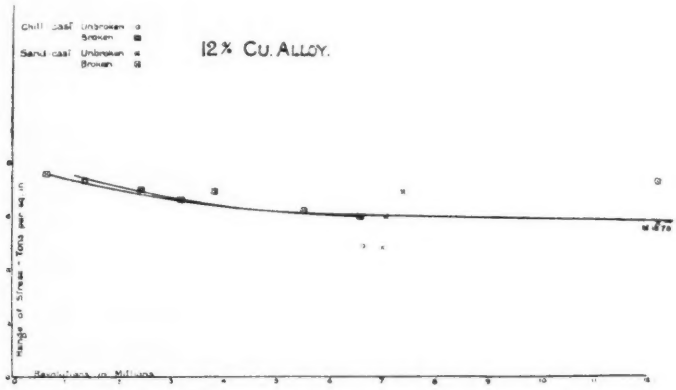

Fig. 54.

Figure 54 indicates that the strength of the sand cast material is practically the same as that of the chill cast material when they are subjected to alternating stresses varying from a maximum compressive to an equal maximum tensile stress, though the elastic limits and ultimate strengths of the chill cast material are considerably higher than those of the sand cast material.

Thus the elastic limits of the specimens tested are approximately

Chill cast ... ... 3.3 tons/sq. in.
Sand cast ... ... 2.25 ,, ,,

while the asymptote of the Wohler curve occurs at a range of stress of about 6 tons/sq. in. for both the sand and the chill cast specimen.

TABLE 4.

RESULTS OF TENSILE TESTS.

CHILL CAST.

Specimen.	Elastic Limit.	Ultimate Stress.	Elongation on 2in.
D1C2	3.4 tons/sq. in.	*7.4 tons/sq. in.	*½%
D1C3	3.2 ,, ,,	13.08 ,, ,,	1½%

* These low results are due to the fact that the specimen was full of small pin holes.

SAND CAST.

Both specimens full of small pin holes.

Specimen.	Elastic Limit.	Ultimate Stress.	Elongation on 2in.
D1S2	2.3 tons/sq. in.	7.725 tons/sq. in.	1½%
D1S3	2.2 ,, ,,	7.12 ,, ,,	1%

TABLE 5.

RESULTS OF WOHLER REPETITION TESTS.

CHILL CAST.

All specimens were sound and free from blow holes and pin holes.

Specimen.	Range of Stress.	Reversals in Millions.	Remarks.
C1C3	7.38 tons/sq. in.	1.392	Broken.
C1C1	7.06 ,, ,,	2.466	,,
C1C4	6.03 ,, ,,	6.609	,,
C1C2	5.00 ,, ,,	6.698	Unbroken.
	7.00 ,, ,,	3.839	Broken.

SAND CAST.

Specimens free from pin holes, but one or two specimens had small blow holes. No fracture, however, occurred at any blow hole.

Specimen.	Range of Stress.	Reversals in Millions.	Remarks.
C1S2	7.04 tons/sq. in.	0.643	Broken.
C1S3	6.67 ,, ,,	3.214	,,
C1S1	4.92 ,, ,,	7.038	Unbroken.
	6.08 ,, ,,	7.098	,,
	7.00 ,, ,,	7.430	,,
	6.30 ,, ,,	5.542	Broken.
C1S4	5.84 ,, ,,	15.730	Unbroken.
	(Allowed to rest for seven days before next test.)		
	7.42 tons/sq. in.	12.256	Broken.

TEST ON WOHLER REPETITION TESTS ON ALUMINIUM ALLOY L8 (12% CU).

A piece of sand cast and chill cast specimen in this series was analysed with the following results:—

	Chill Cast (C1C1).	Sand Cast (C1S1).
Cu	12.00%	12.55%
Sn	Nil.	Nil.
Fe	.69%	.82%
Zn	.05%	Trace.
Si	.38%	.37%

Repetition Tests on Aluminium Alloy (8 per cent. Cu, 6 per cent. Zn).

The results of the tensile tests are tabulated in Table 6, and the stress strain curves are shown plotted in Figures 55 and 56. The results of the Wohler tests are recorded in Table 7 and are plotted in Figure 57.

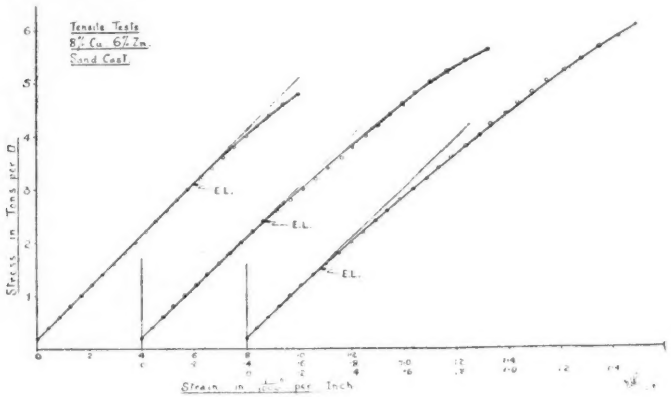

Fig. 55.

It will be noted that the results of the tensile tests are fairly uniform with the exception of the elastic limits of the sand cast specimens, which appear to be very irregular. It will further be noted that the superiority of the chill cast

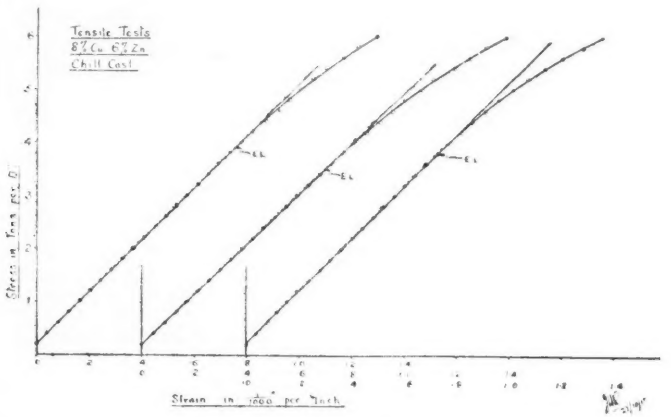

Fig. 56.

specimens over the sand cast specimens is considerably more marked under repeated stresses than under direct tensile stress. As is seen in the tables, there is apparently no direct connection between the asymptotes of the repetition test

curves and the elastic limits and ultimate strengths in the corresponding tensile tests.

	Wöhler Test. Total Range Asymptote.	Average Elastic Limit.	Average Ultimate Stress.
Chill Cast	10.5 tons/sq. in.	3.7 tons/in.^{2}	12.28 tons/in.^{2}
Sand Cast	4.6 ,, ,,	2.3 ,, ,,	8.87 ,, ,,

Pieces of sand cast and chill cast test specimens were analysed and gave the following results:—

	Chill Cast (C_2C_1).	Sand Cast (C_2S_1).
Cu	8.7%	9.54%
Sn	Nil.	Nil.
Fe	.57%	.75%
Zn	5.26%	5.53%
Si	.33%	.35%

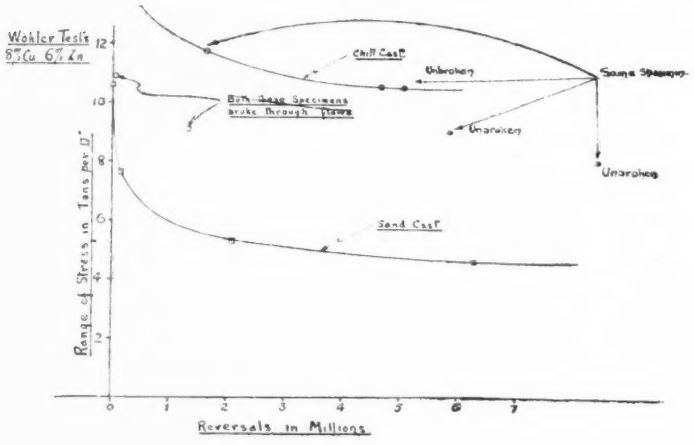

FIG. 57.

TABLE 6.

TENSILE TESTS ON ALUMINIUM ALLOY (8% CU, 6% ZN).

CHILL CAST.

No. of Specimen.	Elastic Limit. Tons sq. in.	Ultimate Stress. Tons sq. in.	Elongation % on 2".	Remarks.
D_2C_1	3.9	12.28	1%	
D_2C_2	3.5	11.88	½%	
D_2C_3	3.8	12.08	½%	
Average	3.7	12.28	.7%	

SAND CAST.

	Tons/in.^{2}	Tons in.^{2}		
D_2S_1	3.1	9.08	½%	Small pin holes in metal.
D_2S_2	2.4	8.52	½%	,, ,, ,,
D_2S_3	1.5	9.00	½%	,, ,, ,,
Average	2.3	8.87	½%	

TABLE 7.

WOHLER REPETITION TESTS ON ALUMINIUM ALLOY (8% CU, 6% ZN).

No. of Specimen.	Range of Stress. Tons in.^{2}	Reversals in Millions.	Remarks.
		CHILL CAST.	
C2C1	8.00	8.380	Unbroken.
	9.04	5.727	,,
	10.50	5.131	,,
	11.78	1.026	Broken.
C2C2	10.96	.075	Broke through small blow hole.
C2C3	9.10	1.334	,, ,, ,,
C2C4	10.56	4.668	Broken.
		SAND CAST.	
C2S1	10.62	.012	Broken. Pin holes in metal.
C2S2	7.64	.142	,, ,, ,,
C2S3	4.65	6.263	,, ,, ,,
C2S4	5.32	2.093	,, Metal free from pin holes on surface.

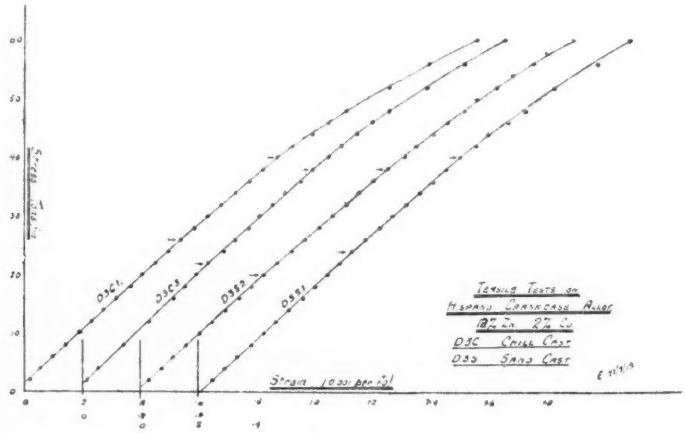

FIG. 58.

Repetition Tests on Aluminium Alloy (12 per cent. Zn, 2 per cent. Cu).

The results of the tensile tests are tabulated in Table 8 and the stress strain curves are shown plotted in Figure 58.

The results of the Wohler tests are tabulated in Table 9 and are plotted in Figure 59.

Considering the stress strain curves it will be seen that in all four cases the curve up to about 4 ton/in.^{2} has been shown as two consecutive straight lines. It is possible that the true stress strain curve for this range may be a slight curve throughout its length or the first portion may be a straight line followed by a curve. The total deviation from the straight line is, however, small, and within reading limits of the extensometer (2in. Ewing) the curve appears to be best represented by two straight lines. The end of the first line is quoted as the primary elastic limit and the end of the upper straight line as the higher elastic limit.

TABLE 8.

No. of Specimen.	Primary Elastic Limit. Tons/in.²	Higher Elastic Limit. Tons/in.²	Ultimate Stress. Tons/in.²	Elongation %2".
CHILL.				
D_3C_1	2.6	4.0	12.04	1.5
D_3C_3	2.2	3.8	13.76	2.5
SAND.				
D_3S_2	2.0	3.8	12.12	2.0
D_3S_1	2.4	4.0	12.20	1.5

From the above results it will be seen that the sand cast and the chill cast specimens give very similar results, the chill cast having possibly a higher elastic limit.

The results obtained from the Wohler tests were not on the whole quite so satisfactory as have been obtained from alloys previously tested, as a number of the specimens broke, owing possibly to defective material or machining, at sections where the stress was not a maximum.

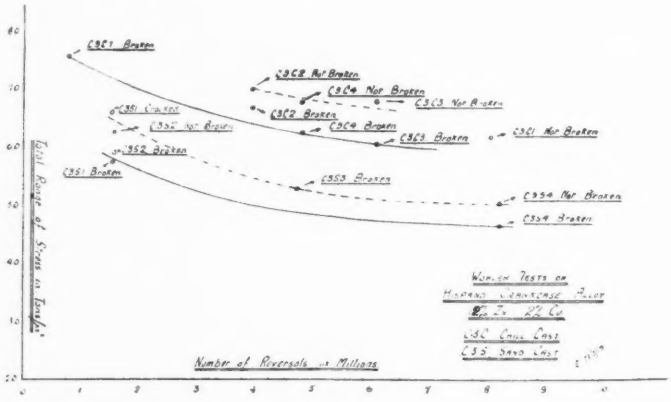

FIG. 59.

In such cases the maximum stress and the stress at the section at which failure occurred are both recorded. One specimen (C_3C_1) was run for eight million complete reversals without fracture, the stress range was then increased and fracture occurred after about three quarters of a million reversals.

Two curves have been drawn for each batch of material; the upper one in each case (shown dotted) possibly represents the conditions for uniformly satisfactory specimens and seems to indicate a safe range for the chill cast of 6.5 tons/in.² and for the sand cast of 5.0 tons/in.².

The lower curves (in full) show the relationship between number of cycles and stress at fracture of the specimens, and these appear to indicate rather lower safe ranges, of the order of 5.9 tons/in.² for the chill cast and of 4.6 tons/in.² for the sand cast.

There does not appear to be any very definite connection between the safe ranges so found and the elastic properties of the alloys, and further, although there is little difference between sand and chill castings, as shown by the static tests, there appears to be a marked difference between the safe ranges of the two classes of material.

TABLE 9.

CHILL.

Specimen No.	Maximum Range of Stress. Tons in.^{2}	Range of Stress at Point of Failure. Tons in.^{2}	Number of Complete Cycles.
C_3C_1	6.16 ± 3.08	—	8,073,300
C_3C_1	7·57 ± 3·785	7·75	774,216
C_3C_2	7·0 ± 3·5	6.7	3,980,232
C_3C_4	6.8 ± 3·4	6.27	4,825,512
C_3C_3	6.8 ± 3·4	6.05	6,112,728
C_3S_1	6.62	5·76	1,544,544
C_3S_2	6.28	5·76	1,580,304
C_3S_3	5.30	5·30	4,833,792
C_3S_4	5.03	4.64	8,218,440

ANALYSES OF THE SPECIMENS.

	Sand Cast (C_3S_4).	Chill Cast (C_3C_3).
Cu	2.17	2.07
Zn	12.13	11.40
Sn	0.06	0.05
Fe	0.73	0.62
Si	0.30	0.27

The Porosity of Aluminium Castings

In order to overcome the porosity of the Hispano Suiza jackets a system of doping or enamelling was introduced; the jacket was filled with the dope and the pressure raised to 70lbs. per square inch. The jackets were then stoved for four hours. In connection with the Puma engine various kinds of enamelling were tried in the jacket to prevent porosity without real success, further, the squadrons had some difficulty with the enamel of the Hispano Suiza engine being dissolved, especially in frosty weather, by the methylated spirit which was put in to prevent the water freezing. It occurred to the author, therefore, that the best solution to the problem would be to try and find some solution, which, either in a mechanical or chemical way, would fill up the pores in a way similar to that in which rusting of cast iron cylinders has been practised for many years. In this case it is not at all unusual to fill the cylinder with water containing salamoniac; the salamoniac causes corrosion to take place in the pores, and the oxide thus formed acts as an effective seal. I therefore tried several solutions which I thought might act on aluminium in a similar way. The most effective of these was ordinary water glass. This, as is well known, especially when diluted with water, contains free sodium hydrate, which is known to act upon aluminium. I therefore carried out many experiments on pistons, cylinders and carburettors, and in every case found that it was quite easy to seal up porous castings.

It was, however, necessary to determine whether any action continued which might in future endanger the casting, and also it was thought desirable to see if in any way the conductivity of the aluminium, after it had been treated with the silicate, was in any way affected. Before the method was suggested I had satisfied myself upon these points, providing that proper care was taken to wash the castings thoroughly after they had been treated.

Messrs. G. and J. Weir used a special jig for holding the cylinder block during testing and silicate treatment. The jacket was first tested with hot water and then filled with hot silicate solution and the pressure raised to 70lb. per sq. inch. Carburettors, induction pipes, etc., can be rendered non-porous by immersion in a hot solution. The oil pipe of the Sunbeam crank case was successfully treated by allowing hot solution to flow through it for a few minutes and then raising the pressure by closing the outlet cock and working

the pump. Many thousands of castings have been successfully treated by this process. Careful washing is required after treatment.

Founding of Aluminium

There are certain difficulties that have to be faced and overcome in the founding of aluminium, and one of the serious problems during the last three years has been how to reduce the very large proportion of scrap so frequently obtained in attempting to produce certain types of castings. The expensiveness of the metal when allied to the high percentage of scrap makes aluminium castings costly and no pains should be spared to find out those alloys which will give the required physical results while at the same time they can be produced efficiently in the foundry. For good and reliable work one of the first essentials, as indeed it is for all good founding, is cleanliness in melting, in the pots and in the moulds. Hardly too much emphasis can be laid upon this. The melting pots, whether of the ordinary plumbago crucible type or iron pots covered with some coating, should be kept clean and in the latter case the coatings should be applied frequently and regularly.

The second point is that of carefully regulating the temperatures. It is not always possible to lay down absolutely and definitely the best temperature to use in pouring any casting, as of necessity the "fluidity" of the metal must depend upon the thinness of the casting to be produced and also upon the intricateness of it. Generally speaking, however, the lower the temperature the better. What is important is that when the temperature has been decided upon and found to be correct for the effective running of any casting it should be carefully controlled, preferably by means of pyrometers, so that the pouring temperature is very nearly the same at each cast; further, the temperature it is allowed to reach in the melting pot should also be the same within reasonable, which means narrow, limits. At present there is hardly sufficient data available to say precisely and definitely what is the effect of rapidity of melting or of allowing metal to "soak" for some time before being poured. If metal is run down rapidly it must of necessity mean a very hot furnace, and there is a danger of the bottom of the pot getting very hot, and of some of the metal reaching a high temperature. With reasonable care, however, even with a very hot furnace, this danger can be avoided. During the war output has been the all-important consideration in foundry practice, and risks have been run that in more leisurely times will hardly be found to be necessary, and it may be, therefore, that aluminium foundry managers will find it will pay in the long run to sacrifice speed to quality and reliability. With such an expensive material as aluminium, and considering the care that had to be exercised in the preparation of moulds and cores, from a commercial standpoint, it clearly will not pay to run any risk in the melting of the metal, which might in any way endanger the finished casting. The cost of actually melting the metal must always be relatively small, and the saving due to increased speed of melting is still smaller, as compared with the cost of the raw material and of the preparation of the mould and cores, and if by paying increased attention to the melting condition the scrap can be in any way diminished, it is clear that economy will soon be effected; there is need for careful investigation in this connection. If the temperature of all the metal can be kept during the whole of the melting below a certain temperature, there is not much danger, but if in prolonging heating it exceeds that temperature the rapidity of oxidisation is greatly increased, and the risk of absorption of silicon from the melting pot or iron from the stirrers is facilitated. To what extent the oxidised aluminium enters into the aluminium or comes to the surface as a scum is by no means easy to determine. Mr. John Rhodin has done very much valuable work in this connection and is still pursuing his investigations. There seems no doubt that very badly "burned" aluminium contains a considerable percentage of aluminium oxide, but it is not at all clear that some of the troubles, such as for example the

occasional brittleness of virgin aluminium, the iron and silicon content of which is not excessive, can be traced to the direct presence of aluminium oxides.

Another and probably even more elusive problem is that of the absorption of gases by aluminium. Before cooling the surfaces of masses of aluminium very frequently give the appearance of occluded gases breaking through the surface. It is not always clear that the correct explanation of the appearance is that gases are escaping. In the surface of the metal it is possible for cooling to take place not perfectly uniformly, and for solidification to take place suddenly at needle points, which give the appearance of small bubbles due to escaping gases.

Whether high temperature melting encourages the absorption of gases, or whether gases, such as nitrogen or the products of combustion from a coke or gas or oil fire, are more easily absorbed is a matter for investigation. It is clearly difficult to control the air and gas in a furnace so that the final products of combustion shall contain no free oxygen, and of necessity they must contain a considerable proportion of nitrogen, and if, as in many furnaces, the gases are allowed to pass over the surface of the metal oxidation may take place, and either N or CO_2 may be occluded by the metal.

If the products of combustion are prevented from coming in contact with the metal but the air admitted then oxidation may take place and N may be absorbed. The possibility of melting under a vacuum upon a large scale is a very doubtful commercial proposition, but it is probable that melting in special pots, which can be easily covered and thus protected from the hot gases, and partially protected from the atmosphere, would reduce any risk of gas absorption and also probably oxidation to a minimum. Certainly the metal could more easily be kept free from dirt and dust. There may be a possibility of hydrogen being absorbed by decomposition of steam, or from other sources, during the manufacture of the virgin metal, and this may affect the final alloy. Whether by mechanical or chemical means or by "soaking" these gases can be eliminated is a matter for inquiry.

Alloys and the Use of Scrap

Difficulties have frequently occurred in the foundries due to inaccuracies of mixture. Unless very special care is taken mistakes are likely to occur in those foundries in which a number of alloys are being made up and used in different types of castings. In such cases it is very desirable that furnaces for melting each kind of alloy should be kept quite separate, and as far removed from each other as possible. When castings are being made from virgin metal, with reasonable care in the weighing out from the stores, mistakes can be avoided. The principal difficulty then arises from the use of scrap, headers, risers, etc., and the possibilities of getting scrap from castings made of different alloys, and the material from headers and risers mixed. As a rule a furnaceman knows the types of castings made from the alloy he melts, and he can recognise scrap made of another alloy, but headers, risers and swarf cannot so readily be checked. For first class work the use of swarf should be avoided and only in any case used when quite clean. In order to prevent the possibility of errors due to wrong mixtures it is also desirable to keep the alloys as simple as possible in constitution. During the war production on a very large scale has been very essential and large numbers of workmen have had to be engaged with comparatively little supervision. Simple alloys that can easily be made and introducing no very serious melting or mixing difficulties have been adhered to, and the results have justified this policy. Special alloys containing particular metals that were supposed to give satisfactory qualities to the alloys have frequently been suggested, but unless the advantages to be derived from their use could be shown to clearly outweigh the disadvantages arising from the increased difficulties in making up the alloys or the possibilities of mistakes in composition the use of these was not encouraged. In the more leisurely times of peace, during which supervision can be better exercised, it may possibly be found that alloys con-

taining such metals as nickel, magnesium, manganese, and other elements, or even rather more iron than is generally thought good, will give valuable properties outweighing the disadvantages of extra care being necessary in the foundry to prevent mistakes, and the greater skill required to prepare the alloys. Very little progress can, however, be hoped for without a very close association between the laboratory and the foundry.

With reasonable care, from 25 to 50 per cent. of scrap can be used without any risk of weakening the casting.

The Foundry and Design

In the design of crank cases, engine cylinders and other large and complicated castings, it is important that before the final design is determined in the drawing office serious consideration should be given to difficulties of castings. Sudden changes of thickness should be avoided as much as possible, and for production on a large scale it is not advisable in large castings to attempt to make castings too thin. An extra one or two millimetres thickness on a casting may make a very large difference in the percentage of scrap produced. Again careful consideration should be given to the "venting" of the mould. It should not be overlooked that the aluminium founder in order to overcome the effects of drawings, and to diminish the risks of cracking, finds it desirable to run the metal as cool as possible consistent with the intricacy of the casting. If possible the temperature of pouring for most of the ordinary alloys should be less than 700° C. If, however, the castings are very thin, or the metal has of necessity to flow a considerable distance in order to fill some part of the casting, higher temperatures may be necessary if mis-runs are to be avoided. Low temperature pouring has, however, one very distinct disadvantage. Unless very great care is exercised in the path the fluid metal is made to take, so as always to force air before it, there is very considerable danger of cooling taking place before the air can escape and shuts or blow holes being formed. The necessity for this care in arranging for the metal always to push the air before it makes it frequently necessary to feed the casting from the bottom of the mould, and thus cores have to be suspended in the mould. Even in many cases when it is not essential to feed from the bottom it is necessary to suspend the cores, and air is likely to be trapped under the cores. In the casting of crank cases very considerable difficulty has been experienced in this direction. In one case the bearings were carried not on a single rib, but on a double rib, which formed with the side of the crank case and the bearing a "box" which had to be formed by a core. To get this core out it was necessary to leave holes in the ribs, and through these it was necessary that the air should escape from under the core. Very considerable difficulty was experienced with blown bosses at the bottom of the crank case, and it seemed reasonably clear that these were due to the real difficulty of getting the air away from what might be called the "box" cores. A somewhat similar difficulty was experienced in the combustion heads of the Arab engines. The long barrel cores were suspended from the top box, and it was difficult to ensure getting the air away from these cores. In some cases, in order to be sure of getting air away, it has been found necessary to pay very particular attention to the venting of the cores and the venting holes have had to be made in the cores themselves.

Cores

Both from the point of view of venting, and also to prevent the cracking of the castings on contraction, the cores have to be made very fragile. In iron founding the temperature of pouring is sufficiently high to cause destruction of the binding materials, such as oils, molasses, or other proprietary articles, which are used as binders. In aluminium founding the temperatures used are not sufficiently high to dissociate these materials, and they are not, therefore, frequently used. To make the cores sufficiently fragile they are made of a sand that is not

too binding and frequently a little sawdust is mixed with the sand; it is in nearly all cases necessary to stove the cores. For cylinder work very great care is necessary to see that the water jacket and valve port are made in boxes that retain their correct shape and they should be dried on flat plates. For good reliable work it is desirable that the cores should be tested by jigs before being placed in the mould.

The contraction of aluminium alloys on cooling can be taken as about 1 in 70 to 1 in 80 or 1.25 to 1.4 per cent. The difficulty of using binding materials in the cores, which will dissociate at the temperature of casting, has already been referred to, and thus it is essential that, where there are large massive cores, as for example the main cores of a crank case or the barrel cores of a cylinder, they shall be sufficiently fragile to crush easily under the contracting stresses set up on cooling.

Gates and Risers

The necessity for pouring at low temperatures makes it essential in nearly all castings for "wide gates" to be used, and if the casting is large it is necessary that there shall be a number of gates into the mould, and generally speaking these should be as large as possible consistent with the thickness of the part of the casting to which they are attached. Figures 60 and 61 show the crank case of the

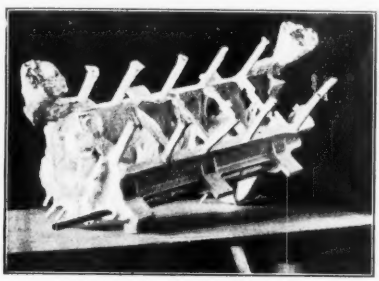

Fig. 60.

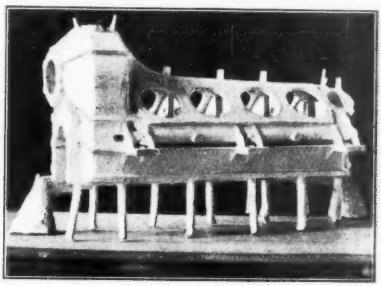

Fig. 61.

Sunbeam Arab engine as taken from the mould. If a gate is connected to a thin part of a casting, and the thickness of the gate where it joins the casting is very much thicker than the casting, there is a danger of drawing and probably cracking. On the other hand if it is too thin the difficulties of too slow running may produce other defects. It can be taken as a guiding principle that wherever there is a considerable change of thickness, or where there is a considerable mass of metal, as for instance near the bearings of a crank case, it will be frequently necessary to have a good riser in order that this part of the casting can be well fed. A large head to the gate will generally help to prevent drawing, and the risers should be sufficiently high, and there should be enough of them to ensure that all heavy parts of the casting are well "fed." Risers also assist in the effective ventilation of the mould, and thus small risers are sometimes found necessary even in the cores. Designers will always do well to consult the aluminium founders about new types of castings as slight modifications in the design may frequently give very considerable assistance to the moulder.

Chills

The use of chills in sand moulds is to be avoided as much as possible, but in many cases they are a necessary evil. Again it is difficult to lay down general

principles, but as in other castings the general object of chills is to induce reasonably uniform cooling in the casting. Chills of brass and cast iron have been used. Where bosses project from a thin surface or at fillets where a thicker mass connects to a thin wall chills are frequently found necessary. Care must certainly be taken to see that chills are not too massive, as it is more than probable that in certain cases cracks were developed due to overchilling. Chills in cores are sometimes found necessary, but particular care should be taken to ensure that when cooling takes place the chills will allow of the necessary amount of contraction.

Die or Chill Castings

The art of die casting, in connection with aluminium alloys, has been considerably developed during this last five years. No mechanical or fluid pressure is, however, used in ordinary aluminium die casting. As the use of considerable pressure has become associated with die casting, it is perhaps better, therefore, to describe the methods as chill casting rather than die casting. Aluminium alloy pistons, parts of crank cases, wheels, and other details have been produced.

Die casting from the point of view of production has considerable advantages over sand casting. Girls and youths can be fairly quickly trained to carry out small work, and with reasonable care, risks of bad castings due to dirt, specks of sand, etc., such as are frequently met with in sand castings, are entirely overcome. In addition the castings have a much finer grain and are stronger than when cast in the sand.

It is not easy to lay down any general principles that have to be observed in designing dies for aluminium. The best methods of pouring, the arrangement of the gates and risers and the methods of ventilating the moulds are all of very considerable importance and sometimes require a good deal of experimenting before successful dies are made. The making of the dies requires very skilled workmanship and can hardly pay unless a very large number of castings are to be produced.

It is generally desirable that the die shall not be too cold when the metal is poured into it, or in other words, that the chilling effect should not be too sudden. It can generally be taken that the opening out of the mould should be made as soon as possible after solidification, and the metal is sufficiently cold to resist the slight tensile stresses that may be set up in drawing the parts of the mould.

To obtain a fine grain in the structure of the material it is only necessary that the time that should elapse to reduce the temperature of the metal should not be sufficient to allow large crystal growth. If, therefore, the casting is in the die sufficiently long to allow complete solidification while at the same time not allowing too great contraction, which would probably cause cracks or draws near the gates and risers, the best results are obtained. Under skilled supervision the workers very quickly develop a sense of the amount of time necessary before the mould should be opened out. For small die castings there seems no doubt that it is undesirable to take molten metal from the actual melting furnace, but rather to have pots preferably in gas fired furnaces, the temperature of the metal in which is kept reasonably constant throughout the day and which can be supplied with molten metal from the melting furnaces.

It is necessary if a die casting is required of any article, that due consideration should be given to its design from the point of view of the possibility of making the die and also the cores in metal. For example, it has been frequently found practically impossible to make certain types of pistons as die castings. A slight modification in the arrangement of the details of the interior of the piston would make it possible to produce them in the die. The internal cores of the die casting must be withdrawn very soon after pouring, and if there are many pieces, serious difficulties are encountered.

It is very doubtful whether any piston that has been used up to the present, which, because of the peculiarities of its design, could not be made in a die, has the slightest advantage over other pistons that have been so designed that they could be cast in a die. Figures 30 to 34 and 62 to 68 are good examples of die castings.

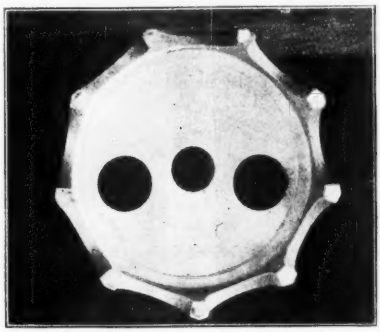

Fig. 62.

Semi-Die Casting

Semi-die casting has been adopted in a number of cases with great success, that is, the outside of the casting is simply a metal chill, while the inside is a sand core. This method can be adopted when it is impossible so to design a casting as to allow the cores to be sufficiently simple that they can be withdrawn easily from the casting, while it is hot. If the sand core is made sufficiently "fragile" in semi-die casting it may not be necessary to remove the casting from the chill very quickly, especially if the gates and risers are so arranged that all the contraction takes place on to the core. The Hispano piston shown in Figures 32 and 35 is a good example of a semi-die casting.

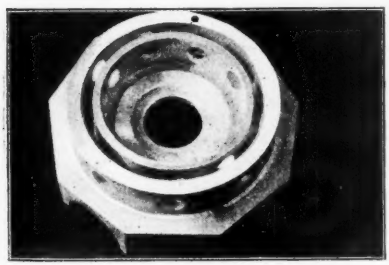

Fig. 63.

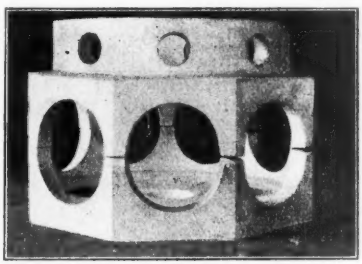

Fig. 64.

Hardeners of Rich Alloys

In making aluminium alloys, such as for example alloys containing Cu, it is generally necessary to make rich alloys, or hardeners as those are frequently called by foundrymen, and troubles sometimes met with in the foundry can be traced to lack of care in the making of these hardeners. The melting point of Cu is about 1,070° C. while that of aluminium is only 635°. The alloy of copper and aluminium containing 34 per cent. of copper has the lowest melting point of about 540°C. A hardener containing 50 per cent. of copper and 50 per cent. of

aluminium is found very convenient for use in practice; its melting point is reasonably low, it is fairly brittle and can therefore be easily broken up, and its simple composition makes it easy to avoid mistakes in the composition of the final alloy.

Undoubtedly the best method of making the copper-aluminium hardener is to melt the copper in a clean pot and add the solid aluminium slowly. As the alloy becomes richer in aluminium its melting point is lowered, and it is possible, therefore, for the final temperature to be lower than the melting point of aluminium and yet the metal will be sufficiently fluid to allow ingoting to be easily done.

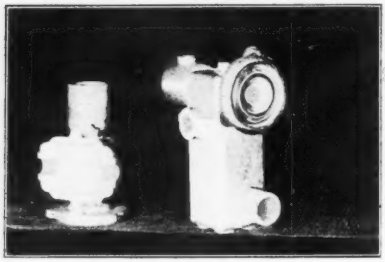

Fig. 65.

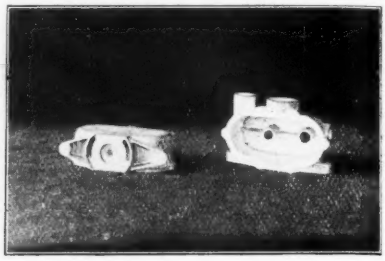

Fig. 66.

Copper, iron and nickel, all of which have a melting point higher than 1,600° C., can be alloyed into aluminium at temperatures well below 1,000° C. by stirring rods or soaking small pieces of metal in the molten aluminium. In the case of nickel, and probably iron, this is perhaps the best method to use to alloy these metals with the aluminium. To melt the iron or nickel and either pour in melted aluminium or add the aluminium in the solid form is hardly to be recommended. Hardeners of copper-iron-aluminium can be made by a thermit process, but great care is required, and the skill necessary to produce a reliable product is beyond that of the ordinary furnaceman. A great deal of research is

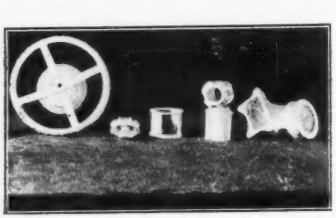

Fig. 67.

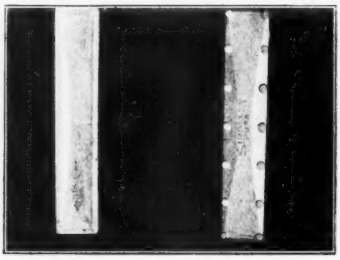

Fig. 68.

required in connection with these alloys, and it is very probable that if they are found really suitable for certain purposes foundries will find it better to have the hardeners prepared under laboratory conditions, or else to buy them from those who make a speciality of their manufacture.

Tin, zinc and magnesium should only be alloyed with the aluminium just before pouring into the moulds. Magnesium is very inflammable and should be plunged quickly below the surface of the molten aluminium by being held in a pair of tongs or by other suitable means. Remelting alloys containing magnesium

does not apparently cause much change in the percentage of this element. The alloys of aluminium and magnesium with or without other metals have not been fully investigated. A great deal requires to be done, and in this connection the association of the foundry and the laboratory is desirable. It is not sufficient to produce alloys of which test pieces, giving excellent results in the laboratory, can be made. Before these can be effectively used in industry it must be possible to produce good castings, and also to make the alloys without risks of failure in the foundry. The advantages of simple alloys in this connection have been referred to, but it may be that more complicated alloys will be found to have properties much more remarkable than those possessed by the simple alloys, and with sufficient expert supervision and laboratory control it may be found possible to use the more complicated alloys and overcome foundry difficulties both from the points of view of alloying and moulding.

Tests for Aluminium Alloy Castings

The strength of aluminium alloy castings depends upon the rate of cooling in the mould as well as upon the composition of the alloy. Specimens cut from thin parts of castings made of the alloy L5 (see Appendix) may have a tensile strength of 14 or 15 tons per square inch, while specimens cut from thick parts may not give more than 11 tons per square inch. Specimens that are cast attached to a particular casting give very variable results, and at the best can only represent some parts of the casting. It is not at all infrequent, due to the difficulties of making satisfactory test specimens in this way, for the test piece to give results not equal to those demanded by the specification, whereas specimens actually cut from the casting themselves, and carefully tested, give results exceeding the demands of the specification. Further, specimens in most aluminium alloys cast in the sand, cast in a half chill mould, or cast in the chill, may give very variable results. It, therefore, soon became apparent that it was necessary to consider seriously how best to test the material from which the casting was made. No test piece can after all do other than represent more or less perfectly the quality of the metal as it is poured from the melting pot; it cannot represent the quality of the casting. To test the material, therefore, is all that is desired. Experience showed that much more uniform results could be obtained, which results more definitely represented the quality of the material, by casting the test piece in a standard chill, 1in. diameter and about 8in. long; specimens could be cast by taking the metal from the melting pot just before the mould is poured. It is desirable that the chill should not be too cold, and its temperature should not be less than, say, 200° C. Small iron ladles, preferably covered with a protective coating of silicate of soda and whiting, should be used for pouring the chill mould.

The tensile tests required in the specifications given in the Appendix are to be obtained from standard specimens cast in these standard chills. Either screwed or collar specimens should be used for aluminium alloy test pieces. Specimens tested in the ordinary Vee grips do not give reliable or satisfactory results. As an example of this the very bad results obtained from specimens cut from the crown of a large piston were brought to my notice. Results obtained by attempting to test flat specimens cut from the crown gave less than 4 tons per square inch. On cutting small screwed end specimens from the actual test pieces, which had only given 4 tons per square inch, and testing them in the axial loading shackles, tensile strengths of 10 tons per square inch were obtained. The specification for the alloy only demanded 8 tons per square inch. Experience has shown that as long as the virgin aluminium and other materials are sufficiently pure, and have been carefully melted, the standard chill specimens do give reliable results as to the quality of the material. The only criticism that can be offered to such test pieces is that there is no guarantee that the specimens were made from the same pot as the casting, unless an inspector is present when every casting is poured and

every test piece made. This is admittedly a serious difficulty unless the foundries can be trusted to act honourably in this matter. I have no hesitation in saying that the best firms can be trusted to carry out the intention of the specifications.

Conclusion

In this paper it has been impossible to do more than describe briefly some of the results achieved, the difficulties that have been overcome, and to deal with the attempts made to determine the important fundamental properties of the materials with which, in this new venture of using aluminium alloys, engineers have had to deal. The final testing laboratory for any new development in engineering is the all important one of every day work and experience; yet it may not unreasonably be claimed that fundamental inquiries undertaken in a scientific manner in the laboratory, in this, as in other matters, have been of very great assistance. On the other hand, good test results in the laboratory are not alone sufficient to indicate the suitability of a material for aeroplane engines.

An alloy may have all the virtues as far as strength and conductivity are concerned, but unless good sound castings can be reasonably easily produced in the sand, or die, it will not be of great use for those aeroplane engine parts which must be cast. Before, however, proceeding to the expensive operations of foundry and engine tests it is desirable that what is required of the alloy should be clearly kept in view and its properties exploited in the laboratory. Ultimate tensile strength at ordinary temperatures is by no means all that is required to indicate the property of an alloy. Its qualities under repetition stresses and at various temperatures should be determined and for pistons and cylinders conductivity is important. Impurities or new alloying metals considerably affect the properties of aluminium alloys. One alloy may be 30 per cent. stronger at 250° C. than another alloy, but if its conductivity is 30 per cent. less, its working temperature as a piston may be higher and the advantage of its increased strength at the given temperature may be of no advantage. If a light alloy can be produced which has the other necessary physical and foundry qualities while having a coefficient of expansion equal to, instead of 2½ times, that of steel, it would be useful for pistons and cylinders and troubles might possibly be reduced.

There is yet a great deal to be done in the development of alloys and foundry methods in order that strong non-porous castings can be produced and organised research in which the laboratory and foundry should co-operate is still required.

No reference has been made in the paper to aluminium alloys which can be forged or shaped by hot or cold work. These are hardly suitable for crank cases, cylinders, and other parts of complicated shapes, but they might be used for bolts and nuts and probably for pistons, connecting rods and other parts. Pistons might be shaped from forgings, but it is doubtful whether the gain in less scrap, etc., would compensate for the extra cost. Alloy connecting rods might be possible although the fact that they would require to be of more ample proportions than steel rods, would introduce difficulties. In this connection the ultimate strengths of these alloys must not be taken as indicating, as for example the ultimate strength of mild steel might do, the safe range of stress in the rod. Duralumin or the N.P.L. (23 + magnesium) alloy rods might possibly be made having an ultimate strength of over 30 tons per sq. inch. At 150° C., however the range of repetition stress must not, for safety, be more than ±7·5 tons divided by some factor of safety. Alloys of 92 to 94 per cent. of aluminium and 6 to 8 per cent. of magnesium also give promise of success for connecting rods. Research, however, is required and this can be best carried out by first having single unit engines specially designed for carrying out long endurance tests.

My very sincere personal thanks, and I venture to suggest the thanks of the members of the Aëronautical Society, are due to Brigadier-General Weir for permission to publish much of the material contained in this Paper, to Lieutenant-

Colonel Jenkin and to Messrs. Willans and Robinson, of Rugby, the Birmingham Aluminium Casting Co., Messrs. G. and J. Weir, of Cathcart, Messrs. Wolseley Motors, Ltd., Messrs. Austin Motors, Ltd., Messrs. Siddeley Deasey, of Coventry, and the Superintendent of the R.A.E., Farnborough, for information willingly given and for photographs and drawings which have made it possible to fully illustrate this paper. Also I desire to express my thanks to Mr. E. Coupland, Mr. L. J. Wills, Mr. J. G. Arthur, and Mr J. L. S. Roberts for their enthusiastic assistance in carrying out the experimental work referred to in the paper.

Appendix I.

Aluminium alloy cylinders have been cast in—

(1) 12% copper, 88% aluminium.
(2) 12% copper, 1% manganese, 87% aluminium.
(3) 8% copper, 1% manganese, 91% aluminium.
(4) 7% copper, 1% tin, 1% zinc, 91% aluminium.
(5) 9% copper, 2% tin, 2% zinc, 87% aluminium.
(6) 10% copper, 1¼% tin.
(7) 10% copper.
(8) 4% copper, 2% iron, .5% magnesium.

The principal difficulty experienced with nearly all these mixes was drawing in the castings and porosity when tested under the hydraulic test. Some good cylinders were cast in all these alloys, but the general result indicated that the best results were obtained with an alloy containing 10% copper, with or without from 1% to 2% tin. As a general result of the experience then obtained, and also of subsequent experience, there seems little doubt that good castings can be made in an alloy containing anything from 6% to 12% copper, with or without the addition of 1% tin. It is not clear that tin is an essential, but most foundry managers appear to think that the addition of 1% to 2% gives an additional fluidity to the material.

Appendix II.

AIR FORCE SPECIFICATION FOR ALUMINIUM ALLOY CASTINGS.

SUITABLE FOR CRANK CASES AND GENERAL USE.

The specific gravity of this alloy is 3.0.

1. *Quality of Material.*—The aluminium used for making this alloy is to assay not less than 98 per cent.

The copper used for making this alloy is to assay not less than 99.3 per cent.

The zinc used for making this alloy is to be of the best quality.

The alloy is to consist of :—

Zinc, not less than 12.5 per cent. or more than 14.5 per cent.
Copper ,, ,, 2.5 ,, ,, ,, 3.0 ,,
Aluminium remainder.

Impurities—

Lead, not more than 0.1 per cent.
Silicon ,, ,, 1.0 ,,
Iron ,, ,, 1.0 ,,

2. *Chemical Tests.*—Samples of the aluminium, zinc and copper, and of the castings, may be selected by the Inspector at the Contractor's expense for chemical analysis, which will be made at the expense of the Government. Should the analysis show that the composition of the material is not within the limits specified in clause 1, the articles represented by the samples may be rejected.

3. *Dimensions.*—The castings are to be accurately in accordance with the drawings, and sufficient allowance is to be made to enable them to be machined where required to the finished dimensions without leaving witness of the cast surface.

4. *Freedom from Defect.*—The castings are to be clean, sound, and free from blow-holes. They are to be capable of being machined satisfactorily and taking a good finish.

Patching.—No patching, plugging, or welding will be allowed unless previous permission in writing has been obtained from the Inspector; such permission will only be given when the defects to be patched are small and do not affect the strength of the casting.

Any casting may be rejected for faults of manufacture or incorrectness of dimensions at any time, notwithstanding that it has been previously passed as complying with this specification by analysis and physical tests.

5. *Mechanical Tests.*—The metal is to comply with the following tests, which are to be carried out by the Contractor at his works in the presence of the Inspector and to his satisfaction.

Tensile Test.—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in clause 6, must give the following results :—

Ultimate strength not less than 11 tons per square inch.
Elongation ,, ,, 4 per cent.

The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

The ultimate strength of this alloy should be over 12 tons per square inch, and the alloy will not be considered first rate till this strength is attained.

6. *Provision of Test Samples.*—At least one sample is to be cast to represent each crank case or other large casting. The number of samples for small castings is to be settled by the Inspector, so that all the alloy used is tested. The samples are to be cast from the same ladle as the castings and are to be poured first.

The samples are to be 1in. in diameter and from 7in. to 9in. long. They are to be cast in iron chills which have been heated before they are filled. The bottom of the chill is to be closed with a clay or sand plug, not with a metal end.

7. *Marking.*—All castings accepted by the Inspector are to be marked as he may direct.

8. *Rejections.*—All castings rejected by the Inspector are to be broken up or marked for identification to the satisfaction of the Inspector, and are not to be tendered again to any Government Department without giving written information to that Department or their Inspector concerning the previous rejection.

9. *Inspection.*—The Contractor is not to supply any castings which have been previously rejected by any Government Inspection Department without giving written information to the Inspector about the previous rejection. The Inspector is to have free access to the works of the Contractor at all reasonable times; he is to be at liberty to inspect the manufacture at any stage and to reject any material that does not conform to the terms of this specification.

10. *Facilities.*—The Contractor is to supply the material required for testing without additional charge, and at his own cost furnish and prepare the necessary test pieces, and supply labour and appliances for such inspection and testing as may be carried out on his premises in acordance with this specification. Failing approved facilities at his own works for making the prescribed tests, the Contractor is to bear the cost of carrying out the tests elsewhere.

SPECIFICATION FOR 12% COPPER-ALUMINIUM ALLOY CASTINGS.

The specific gravity of this alloy is between 2.83 and 2.94.

1. *Quality of Material.*—(*a*) The aluminium used for making this alloy is to assay not less than 98 per cent.

(*b*) The copper used for making this alloy is to assay not less than 99.3 per cent.

(*c*) The alloy is to consist of :—

Copper, not less than 11 per cent. or more than 13 per cent.
Aluminium, remainder.

(*d*) Impurities—

Zinc, not more than 0.1 per cent.
Lead ,, ,, 0.1 ,,
Silicon ,, ,, 1.0 ,,
Iron ,, ,, 1.0 ,,

6. *Mechanical Tests.*—(*a*) The metal is to comply with the following tests, which are to be carried out in the presence of the Inspector and to his satisfaction.

(*b*) *Tensile Test.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in clause 6 (same as that of above specification), must give the following result :—

Ultimate stress not less than 9 tons per square inch.

(*c*) The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

SPECIFICATION FOR ALUMINIUM ALLOY CASTINGS.

The specific gravity of this alloy is 2.95.

1. *Quality of Material.*—(*a*) The aluminium used for making this alloy is to assay not less than 98 per cent.

(*b*) The copper used for making this alloy is to assay not less than 99.3 per cent.

(*c*) The alloy is to consist of :—

Copper, not less than 9.0 per cent. or more than 11.0 per cent.
Tin ,, ,, 0.5 ,, ,, ,, 1.5 ,,
Aluminium, remainder.

(*d*) Impurities—

Lead, not more than 0.1 per cent.
Silicon ,, ,, 1.0 ,,
Iron ,, ,, 1.0 ,,

2. *Chemical Test.*—Samples of the aluminium, tin and copper, and of the castings, may be selected by the Inspector at the Contractor's expense for chemical analysis, which will be made at the expense of the Government. Should the analysis show that the composition of the material is not within the limits specified in clause 1, the articles represented by the samples may be rejected.

5. *Mechanical Tests.*—(*a*) The metal is to comply with the following tests, which are to be carried out in the presence of the Inspector and to his satisfaction.

(*b*) *Tensile Test.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in clause 6 (same as that of above specification), must give the following result :—

Ultimate strength not less than 9 tons per square inch.

(*c*) The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

7. *Hydraulic Test.*—(*a*) All cylinder castings and others which are required to be tight are to be tested for porosity by means of water, methylated spirits or petrol. The test is to be carried out in an approved manner to the satisfaction of the Inspector.

(*b*) Castings which have been tested are to be marked to show the result of this test as the Inspector may direct. All castings which in the opinion of the Inspector are too porous for use will be rejected. Castings which are only slightly porous will be accepted subject to their proving tight after subsequent doping.

8. *Doping.*—(*a*) Doping may be carried out by the Contractor or at the machine shop as may be arranged. If the Contractor dopes the castings he is to do so in an approved manner to the satisfaction of the Inspector.

SPECIFICATION FOR 7:1: ALUMINIUM ALLOY CASTINGS.

The specific gravity of this alloy is between 2.87 and 2.93.

1. *Quality of Material.*—(*a*) The aluminium used for making this alloy is to assay not less than 98 per cent.

(*b*) The copper used for making this alloy is to assay not less than 99.3 per cent.

(*c*) The alloy is to consist of :—

Copper, not less than 6.0 per cent. or more than 8.0 per cent.
Tin ,, ,, 0.5 ,, ,, ,, 2.0 ,,
Aluminium, remainder.

(*d*) Impurities—

Lead, not more than 0.1 per cent.
Zinc ,, ,, 1.0 ,,
Silicon ,, ,, 1.0 ,,
Iron ,, ,, 1.0 ,,

5. *Mechanical Tests.*—(*a*) The metal is to comply with the following tests, which are to be carried out in the presence of the Inspector and to his satisfaction.

(*b*) *Tensile Test.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in clause 6 (same as that of above specification), must give the following result :—

Ultimate stress not less than 8 tons per square inch.

(*c*) The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

APPENDIX III.

ANALYSES OF CASTINGS.

CRANK CASE ALLOY.

Copper	2.66	per cent.
Iron	.55	,,
Zinc	12.99	,,
Silicon	.22	,,

ANALYSES OF SUNBEAM ARAB (10 Cu., 1¾ Tin) CYLINDERS.

Copper	9.97 to 12.04—1.95	per cent.
Tin	1.16 to 1.47—1.27	,,
Iron	.62 to 1.01— .69	,,
Silicon	.22 to .30— .24	,,
Zinc	Nil to .41— .10	,,

Strength at 250° C. chill cast at more than 9 tons per square inch.

EXPERIMENTAL ARAB CYLINDERS.

Copper	7.36 per cent.
Zinc	.26 ,,
Manganese	.98 ,,
Iron	.52 ,,
Silicon	.29 ,,

This gave 7.76 per square inch and 2.5 per cent. elongation.

TYPICAL EXAMPLE OF ANALYSIS FOR 12 PER CENT. COPPER PISTONS, SAND CAST.

Copper	11.24 per cent.
Iron	.69 ,,
Silicon	.28 ,,

ANALYSIS OF HISPANO SUIZA JACKET.

Copper	7.84 per cent.
Zinc	6.33 ,,
Iron	.44 ,,
Silicon	.27 ,,

HISPANO SUIZA CRANK CASE.

Copper	2.2 per cent.
Iron	.62 ,,
Zinc	11.03 ,,
Silicon	.27 ,,
Aluminium	85.88 ,,

LYNITE PISTON.

Copper	8.96 per cent.
Iron	1.30 ,,
Magnesium	.27 ,,
Silicon	.36 ,,
Aluminium	89.11 ,,

The piston was clean sound casting, and showed no porosity at a pressure of 1,000lbs. per square inch.

B.H.P. CYLINDER CASTING IN ZINC ALLOY (DISCARDED).

Copper	2.05 per cent.
Zinc	11.35 ,,
Iron	.66 ,,
Silicon	.22 ,,
Aluminium	85.72 ,,

	Benz Piston.	Benz Piston Alloy made at Birmingham.	
		G1.	G2.
Copper	6.02	5.44	5.58
Tin and Lead ...	Nil	Nil	Nil
Iron	1.4	1.41	1.47
Zinc	12.13	12.27	12.34
Manganese ...	Nil	Trace	Trace
Magnesium ...	Trace	Trace	Trace
Silicon	.31	.31	.31

The strength of G1 at 300° C. was 4.08 tons per square inch.

At ordinary temperatures 13.91 tons per square inch.

CLERGET PISTON.

Copper	11.63 per cent.
Silicon	5·39 ,,
Iron	·46 ,,
Aluminium	81.30 ,,
Nickel	·91 ,,
Arsenic	Nil
Zinc	Nil
Silicon	·31 ,,

APPENDIX IV.

THE THERMAL CONDUCTIVITY OF ALUMINIUM ALLOYS.

The absolute coefficient of thermal conductivity of Ingot Aluminium may be taken as approximating to 0.50, but it varies very considerably in different samples. Dr. Ezer Griffiths obtained from two samples the following values for the density and mean thermal conductivity between 1.15° and 350° C. :—

ANALYSES OF ALUMINIUM.

	Si.	Fe.	Cu.	Zn.	Al by difference.	Density.	Mean Thermal Conductivity.
(1)	0.21	0.27	0.10	Trace	99.42	2.569	0.442
(2)	0.14	0.38	Trace	—	99.48	2.70	0.497

The difference in conductivity indicated by the difference in density may be due to fine pores in the less dense specimen.

The absolute thermal conductivity of alloys of aluminium shows, however, a much greater variation, and is very much affected in certain alloys by annealing, as the following table shows :—

Analysis (per cent.).					Thermal Conductivity.	
Cu.	Mn.	Sn.	Zn.	Al.	Without annealing.	After annealing.
7.		1.	1.	91.	0.35 to 0.40	0.39 to 0.40
14.	1.			85.	0.24 to 0.295	0.33 to 0.38
7.91		Fe .82			.35 to .38	.40 to .42
8.18		Fe .82			.34 to .36	.38 to .39

EXTENSION OF THE ACTIVITIES OF THE SOCIETY

The Council have had under consideration the extension of the activities of the Society to cover a wider range of subjects and to interest a greater proportion of those connected with technical aeronautics, not only in London, but also at other centres.

This extension has now become possible and it is desired to receive suggestions as to the form it should take.

The scheme at present under consideration is outlined below. This scheme, and modifications or extensions of it, will be discussed at an informal meeting in the Library of the Society at 7.0 *p.m., on Tuesday, September 15th,* 1925.

Written contributions are invited from those who will be unable to attend. The Society of British Aircraft Constructors, the Royal Aero Club, and the Air League have been asked to contribute to this discussion.

The meeting has no executive power, but will no doubt bring out points which will be of valuable assistance to the Council.

The Council's objects are:—

(1) To extend the range of subjects dealt with to include the practical questions of construction, design and flying, in addition to those of a more purely scientific and operational nature which are now more fully dealt with.

(2) To increase the proportion of those engaged in technical aeronautics who are interested by the proceedings of the Society. It is probable that this increase will mainly be in the direction of those holding junior technical or flying posts and whose finances make membership of the Society in one of the existing grades somewhat difficult.

(3) To assist those living at a distance from London to hear lectures and to take part in discussions.

The limitations to the extension of the activities of the Society are set by financial considerations. Any increase in expense is only possible if it can be met by increased revenue resulting from the greater interest created by the work of the Society.

The present forms of activity are:—

(1) Lectures in London. These reach comparatively few, except when reported in the Journal.

(2) Discussions in London. So far these have been well attended and have produced interesting material.

(3) The Journal—which contains a full record of the lectures and discussions and a certain amount of additional material. It is thought that the latter should be considerably increased.

The cost of meetings in London is small unless the subject is of such interest as to justify using the Society of Arts and that is only done where the interest justifies the greater expense. The material printed in the Journal, as a result of additional meetings, is probably fully justified by its value.

It is hoped to arrange in London a number of informal meetings for the discussion of suitable subjects. These will be selected so as to allow a detailed discussion by those engaged upon or interested in a particular aspect of the work, rather than treatment in a more general way, which is necessary in a

lecture covering a wider subject. A summary of these discussions would normally appear in the Journal, but the cost of each discussion will be unimportant.

The cost of repeating in the provinces lectures or discussions already prepared for London will be comparatively small, particularly if it is possible to make arrangements with some interested firm for accommodation. Once a lecture with its appropriate slides has been prepared, it involves little trouble to repeat it, either by the author or by someone detailed by him.

To extend membership to include those who are not at present able to join the Society, involves the adoption of a class of members with subscriptions corresponding barely to their minimum cost to the Society. This proposal might take the form of membership to entitle the holder to the following benefits :—

(1) To attend and take part in all lectures and discussions.

(2) Not to receive the Journal, but to purchase any copy of it at cost price.

(3) No technical qualification would be required for this grade and membership of it would carry no technical distinction.

The arrangements outlined above will probably make satisfactory provision for those members who are able to reach the Offices of the Society without difficulty. To give similar facilities to those living in other parts of the country, it has been suggested that local branches should be formed in areas, so selected as to include centres of activity within reasonable distance. The time expended upon travelling is such a deterrent even in the case of members living in London, that it is thought doubtful whether a member living in one town would attend meetings in another, which must, in most cases, be at a considerable distance. On the other hand, many works already have engineering societies which are very well attended and perform extremely useful work. It is thought better to encourage the formation of these Works' Societies and to assist those existing ones which care to become affiliated to the Society. The extent to which members of these local organisations can benefit from the present activities of the Society is comparatively small, and it is thought that subscriptions by local members should be expended almost entirely for the benefit of their individual local centres. The assistance which the Society could give would then take the form of :—

(1) Assisting in the arrangement of lectures and discussions or for the repetition of lectures and discussions already given elsewhere. The Society in London may be better in touch with those who would be able to give the best lecture on a selected subject than would be the Secretary of the local organisation. The arrangements of lectures to be given by officers detailed by the Air Ministry are probably more easily made through London than direct.

(2) Members would be entitled to attend all lectures and discussions of the Society when they are in London.

(3) Members would have the use of the Society's Library for reference, but not for borrowing.

(4) One or more copies of the Journal would be supplied to each local Society for reference and local members could purchase, through their local Society, copies of the Journal at cost price.

In exchange for these benefits, the local Society would be expected to pay a small annual affiliation fee (of, say, five guineas, or, possibly, on the basis of, say 1/- a head of membership). Members of the R.Ae.S. would presumably be entitled to attend meetings of the local Societies without additional subscription.

Local Societies would then fix their own subscriptions and administrate their funds entirely at their own discretion.